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Cost estimating relationships (U.S. fleet/USSR fleet)

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Cost estimating relationships based on the observed (reported) cost and weight (full load displacement) of U.S. Navy ships are derived for the purpose of applying these cost estimating relationships to ships in the fleets of both the U.S. and USSR. This application results in broad, general comparisons that, in the aggregate, provide useful trend comparisons. These cost estimating relationships produce varying results on a class basis, but within each group or category of ships the class overestimates tend to be offset by class underestimates to yield a relatively small category error. (Continued)

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20. ABSTRACT (Continuation)

This paper updates major portions of IDA Paper P-1530, "Simple Relationships for Estimating Procurement Cost of U.S. Navy Ship Categories," dated March 1982.

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IDA PAPER P-1732

COST ESTIMATING RELATIONSHIPS FOR U.S. NAVY SHIPS

Revision of IDA Paper P-1530

William J. E. Shafer

September 1983

Prepared for
Office of the Under Secretary of Defense for Research and Engineering
Special Assistant for Assessment

IDA

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PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Special Assistant for Assessment, Office of the Under Secretary of Defense for Research and Engineering, under Contract MDA 903 79 C 0018. The study was under the cognizance of Dr. Paul J. Berenson.

This paper is one of a continuing series of studies at IDA on various comparisons of U.S. and USSR military RDT&E and procurement programs. One aspect of these comparisons involves determination of investment balance. Because information about Soviet weapon costs is limited, one way to compare the U.S./USSR balance is to base estimates on other data that are observable or can be determined by other means.

Cost estimating relationships based on the observed (reported) cost and weight (full load displacement) of U.S. Navy ships are derived for the purpose of applying these cost estimating relationships to ships in the fleets of both the U.S. and USSR. This application results in broad, general comparisons that, in the aggregate, provide useful trend comparisons. These cost estimating relationships produce varying results on a class basis, but within each group or category of ships the class overestimates tend to be offset by class underestimates to yield a relatively small category error.

This paper updates major portions of IDA Paper P-1530, *Simple Relationships for Estimating Procurement Cost of U.S. Navy Ship Categories*, dated March 1982.

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SUMMARY

An initial cut at estimating the procurement cost of categories of naval ships is to use cost-weight relationships. These relationships are useful for estimating the procurement cost of naval ships on an aggregate basis rather than forecasting the cost of individual ships or classes of ships. The cost estimating relationships (CERs) in this paper were developed to compare the procurement cost of U.S. and Soviet naval ships. The estimates of Soviet ship costs are simply what cost the U.S. would incur if ships of the same displacement as Soviet ships were procured in the U.S.

In developing the cost estimating relationships, the following procedures and assumptions were applied:

1. Only costs for ships already delivered were used except for the Aegis cruisers and Ohio class SSBNs.
2. All cost data came from the U.S. Naval Sea Systems Command.
3. Costs were converted to constant Fiscal Year 1983 dollars.
4. Costs for ship conversions were excluded.
5. A least-squares method was used to determine the regression equation.
6. CERs which intersected the displacement axis (abscissa) were disallowed and the CER was forced to go through the origin (i.e., a negative cost estimate for a positive displacement was not allowed).
7. A constant incremental cost over a specified range of ship displacement was assumed for the procurement cost of a nuclear powered ship relative to that of a non-nuclear powered ship of the same category.

The cost estimating relationships derived for each category of ships are presented in Table S-1. Where the least error CER (least average ship class absolute error) is a form other than linear, the linear CER also is displayed. In addition, Table S-1 displays the total observed cost, the total estimated cost, and the percent difference between the observed and estimated costs for each ship class and category. The estimate error for a category of ships is generally less than the average ship class absolute error for classes comprising the same category due to cancellation effects. For example, using the least error CER the error for the Aircraft and Helicopter Carriers category is 1.3 percent, whereas the individual ship class errors range from 2.2 to 11.7 percent, for an average ship class absolute error of 5.9 percent.

On balance, these simple CERs can provide an accurate estimate of the aggregate procurement cost at the force or fleet level. The estimated aggregate procurement cost of the 60 classes of ships comprising the 11 ship categories using these CERs is within one percent of the observed aggregate procurement cost. These CERs should not be used to predict the cost of individual ships or new classes of ships.

Table S-1. SHIP COST ESTIMATING RELATIONSHIPS
(Cost is in Thousands of FY 1983 Dollars)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displace-ment-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Total Observed Cost by Class	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Least Error CER**	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Linear CER***
Aircraft and Helicopter Carriers															
CV	59	4	1955	79,650	1,491[a]	1,496	5,984	1,671.2	6,685	+11.7		1,645.6	6,582	+10.0	
	63	3	1961	80,300	1,832	1,753	5,259	1,686.5	5,060	-3.8		1,659.0	4,977	-5.4	
	67	1	1968	80,800	1,737	1,737	1,737	1,698.3	1,698	-2.2	$C = 12.3D^{1.122}$	1,669.3	1,669	-3.9	C = 20.66D
LHA	1	5	1976	39,300	847.1	818.2	4,091	756.5	3,783	-7.5		811.9	4,060	-0.8	
LPH	2	7	1961	18,300	336.1	308.3	2,158	320.9	2,246	+4.1		378.1	2,647	+22.6	
Total							19,229		19,472	+1.3			19,935	+3.7	
CVN	65	1	1961	91,000	3,065	3,065	3,065	2,604	2,604	-15.0	$C = 670 + 12.3D^{1.122}$	2,610	2,610	-14.8	C = 730 + 20.66D
	68	2	1975	94,400	2,974	2,680	5,360	2,686	5,372	+0.2		2,680	5,360	0	
Total							8,425		7,976	-5.3			7,970	-5.4	
Attack Submarines															
SSN	578	4	1957	2,860	484.9	338.3	1,353	335.8	1,343	-0.7					
	585	6	1959	3,500	478.6	356.7	2,140	364.8	2,189	+2.3					
	594[b]	14	1961	4,450	874.0	543.1	7,603	407.6	5,706	-24.9	C = 206 + 45.3D				
	637	37	1967	4,582	443.3[c]	421.3	15,588	413.8	15,311	-1.8					
	688	12	1976	6,927	853.1	518.2	6,218	520.1	6,241	+0.4					
Total							32,902		30,790	-6.4					
SS	576	1	1956	2,388	168.2	168.2	168	154.2	154	-8.3					
	580	3	1959	2,639	227.4	165.4	496	165.4	496	0	C = 46 + 45.3D				
Total							664		656	-2.1					
Fleet Ballistic Missile Submarines															
SSBN	598	5	1959	6,688	1,223.3	802.7	4,014	660.5	3,303	-17.7		626.6	3,133	-21.9	
	608	5	1961	7,880	1,004.5	710.4	3,552	724.8	3,624	+2.0	$C = 392e^{.078D}$	728.4	3,642	+2.5	C = 30 + 89.2D
	616	31	1963	8,220	1,029.1	609.8	18,904	744.3	23,073	+22.1		763.2	23,659	+25.2	
	726	7	1981	17,500	2,453.8	1,591.6	11,141	1,535.0	10,745	-3.6		1,591.0	11,137	0	
Total							37,611		40,745	+8.3			41,571	+10.5	
Destroyers, Frigates, and Patrol Combatants															
DD	931	18	1954	3,960	285.8	187.9	3,382	160.9	2,896	-14.4					
	963	30	1975	7,924	445.2	307.7	9,231	310.9	9,327	+1.0					
FF	1006/1021	13	1954	1,914	138.9	75.7	984	83.5	1,086	+10.3					
	1033	4	1959	1,750	70.2	67.5	270	77.3	309	+14.5	C = 11.1 + 37.8D				
	1037	2	1963	2,690	123.5	114.4	229	112.9	226	-1.3					
	1040	10	1964	3,344	173.0	148.5	1,485	137.6	1,376	-7.3					
	1052	46	1969	4,100	341.5	144.2	6,633	166.2	7,645	+15.3					
PG	84	17	1966	260	31.1[d]	24.6	418	21.0	357	-14.6					
Total							22,632		23,222	+2.6					

*LT = Long Tons.

**Least error CER is defined as the CER that has the least average ship class absolute error.

***Linear CER is displayed where the least error CER is another form.

Table S-1. (Continued)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displace-ment-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Total Observed Cost by Class	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Least Error CER**	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Linear CER***
Guided Missile Cruisers, Destroyers, and Frigates															
CG	16	9	1962	8,074	601.0	435.3	3,918	418.8	3,769	-3.8					
	26	9	1964	8,500	522.7	412.1	3,709	436.4	3,928	+5.9					
DDG	2	23	1960	4,500	343.1	255.9	5,886	271.5	6,245	+6.1	C = 86.1 + 41.2D				
	37[e]	10	1960	5,960	448.4	356.7	3,567	331.7	3,317	-7.0					
FFG	1	6	1966	3,600	234.4	187.6	1,126	234.4	1,406	+24.9					
	7	10	1977	3,605	630.9	279.9	2,799	234.6	2,346	-16.2					
Total							21,005		21,011	0					
AEGIS CG															
CG	47	7	1983	9,200	1,368.7	1,076.8	7,538	1,076.8	7,538	0	C = 698 + 41.2D				
Guided Missile Cruisers (Nuclear Powered)															
CGN	9	1	1961	17,100	2,232.6	2,232.6	2,233	a	-	-					
	25	1	1962	9,200	1,052.4	1,052.4	1,052	855.0	855	-18.7					
	35	1	1967	8,800	831.5	831.5	832	838.6	839	+0.8	C = 476 + 41.2D				
	36	2	1974	10,530	902.8	852.2	1,704	909.8	1,820	+6.8					
	38	4	1976	11,000	928.4	795.7	3,183	929.2	3,717	+16.8					
Total							9,004		7,231	+6.8					
Amphibious Ships															
LST	1171[f]	7	1957	7,804	162.4	98.4	689	95.2	666	-3.3		138.9	972	+41.2	
	1179	20	1969	8,400	282.4	112.2	2,244	103.2	2,064	-8.0		149.5	2,990	+33.2	
LSD	28	8	1954	12,000	220.1	153.6	1,229	167.8	1,342	+9.2		213.6	1,709	+39.1	
	36	5	1969	14,000	161.1	155.6	778	219.8	1,099	+41.3	$C = 33.2e^{.135D}$	249.2	1,246	+60.2	C = 17.8D
LPD	1	3	1962	14,651	308.7	290.5	872	240.0	720	-17.4		260.8	782	-10.2	
	4	11	1965	16,913	g	245.5	2,701	325.6	3,582	+32.6		295.7	3,249	-20.4	
LCC	19	2	1970	17,000	632.1[h]	490.3	981	329.5	659	-32.8		302.6	605	-38.3	
Total							9,494		10,132	+6.7			11,553	+21.7	
Underway Replenishment Ships															
AE	21	5	1956	17,450	138.4	117.8	589	139.1	696	+18.1		134.1	671	+13.8	
	26	8	1968	19,937	189.4[i]	180.8	1,446	147.5	1,180	-18.4		147.8	1,182	-18.3	
AF	58	2	1955	15,540	128.7[j]	128.9	258	133.0	266	+3.2		123.5	247	-4.2	
AFS	1	7	1963	16,049	160.5	140.7	985	134.6	942	-4.3		126.3	884	-10.2	
AO	143	6	1953	39,800	209.6	172.4	1,034	235.6	1,414	+36.7	$C = 92.2e^{.024D}$	257.8	1,547	+49.5	C = 37.4 + 5.54D
	177	3	1981	27,500	251.6	207.8	623	176.3	529	-15.2		189.7	569	-8.7	
AOE	1	4	1963	53,600	452.9	423.6	1,694	326.1	1,304	-23.0		334.2	1,337	-21.1	
AOR	1	7	1969	41,350	224.0	201.0	1,407	244.3	1,710	+21.5		266.4	1,865	+32.5	
LKA	113	5	1968	18,657	175.3	147.6	738	143.1	716	-3.0		140.7	704	-4.7	
Total							8,774		8,757	-0.2			9,006	+2.6	

*LT = Long Tons.

**Least error CER is defined as the CER that has the least average ship class absolute error.

***Linear CER is displayed where the least error CER is another form.

[a]CGN-9 was not included in deriving the CER, thus the CER is not applicable.

Table S-1. (Continued)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displace-ment-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Estimated Cost	Percent Difference	CER
Destroyer and Submarine Tender									
AD	37	2	1967	20,500	354.5	325.2			
	41	4	1980	20,500	391.5[k]	407.6			
AS	31	2	1962	19,819	351.4[l]	355.4	Data was too clustered to produce a reasonable CER.		
	33	2	1964	21,000	408.3	359.8			
	36	2	1970	23,493	324.2	286.1			
	39	3	1979	22,646	450.7	425.2			

*LT = Long Tons.

[a]Low lead ship cost is because of the four ships in this class, the first and third ships were built at Newport News and the second and fourth ships were built at the New York NSY. These latter ships were more costly than the lead ship built at Newport News.

[b]Data includes the Thresher (SSN-593) which was lost during sea trials. This class was omitted from the derivation of the CER.

[c]The lead ship was built by Electric Boat, however, the first four follow-on submarines were built by four different shipyards, (two NSYs and two PSYs) all at a higher cost than the lead ship.

[d]The first eight ships in this class were built by the same shipyard. Follow ships three and four were about 80 percent more costly than the lead ship. The remainder of the ships were built at about 56 to 74 percent of lead ship cost by two builders.

[e]The DDG-37 class was originally classified as the DLG-6 class.

[f]Although the LST-1171 is the lowest hull number of this class, the class is named for the Suffolk County (LST-1173) which is designated the lead ship of the class.

[g]The first three ships of this class were authorized and funded in the same year. The cost data available did not identify costs by hull number; therefore, the cost for the lead ship cannot be determined.

[h]The LCC-19 was built by the Philadelphia NSY and the follow ship by Newport News at about 55 percent of the lead ship cost.

[i]Ships of the AE-26 class were authorized and funded at a rate of two per year, both built by the same builder. It appears that the cost of the first two ships were about equally divided; therefore, a typical lead/follow ship cost relationship does not exist.

[j]Same situation as for the AE-26 class.

[k]Two of the three follow ships cost more to build than the lead ship.

[l]The two ships of this class were built by two shipyards with the follow ship more costly than the lead ship.

INTRODUCTION

There are many varieties of comparisons of U.S. and Soviet naval activities. Obviously, an overall comparison of capabilities is desired but it is not feasible. Instead a set of comparisons must be substituted. One is the aggregate comparison of the annual cost of procurement of ships in the U.S. and Soviet fleets. Another estimates the asset value of the ships in each active fleet. This paper provides a way of developing both these estimates. Another comparison is of the numbers of ships and their displacements. However, both quantitative and qualitative dimensions of the two fleets are reflected in the procurement costs. To permit the comparisons in comprehensible terms, U.S. currency is used for both the U.S. and USSR. Thereby, one can measure the overall size and direction of both U.S. and Soviet naval programs in resource terms. To remove most of the effects of inflation; costs are expressed in constant dollars.

The estimates of procurement costs of Soviet ships are based on algorithms developed from U.S. historical ship procurement costs. Cost estimates of Soviet ship procurement do not measure the manufacturing efficiencies in Soviet shipyards; they are estimates of what it would cost to produce Soviet ships in U.S. shipyards using U.S. production technology. These dollar costs are not likely to represent the actual Soviet ship procurement costs nor the burden of such procurement on the Soviet economy.

This paper records the derivation of simple ship cost estimating relationships (CERs) based on ship displacement. A similar set of CERs was published in Table S-1 of IDA Paper P-1530

[Reference 1]. The categories (groups) of ships used to derive the CERs in P-1530 and in this paper are essentially the same except for minor variations. The changes in the derivation of ship CERs from P-1530 are addressed in the following paragraphs.

There are three major variations. Reference 1 presented only a linear relationship between ship full load displacement and procurement cost for each set of categories. Here two additional mathematical forms of equations to describe the ship displacement/procurement cost relationship are also tested. When either of these equations provided a better fit (the least average ship class absolute error) this is presented for each ship category. The linear relationship is also displayed. A least squares technique was used in all cases to fit equations to the data.

An attempt was made to include the year of IOC as a time-dependent variable. The linear multiple regression equation that resulted from converting the logarithmic equation to a power form is given in paragraph D2 of the Methodology Section. The time-dependent variable (the last two digits of the year of the ship class IOC minus 81)[1] was included to account for the effect of cost increase from one generation or class of ships to the next. This cost increase is commonly believed to result from the incorporation of progressively advancing and more costly technology. However, the linear multiple regression analysis yielded spurious results, and the equations are not included.

The second change is that the costs in P-1530 are expressed in FY 1979 dollars; whereas, the costs in this paper are in FY 1983 dollars. TOA deflators published by OSD dated 2 February 1982 were used to convert "then-year" dollars to FY 1983 dollars.

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[1]The year 1981 was chosen as a reference year for the time-dependent variable.

Third, there is a difference in the composition of the ships comprising each group of ships. The lead ship has been included in the data upon which the CER is derived in this paper, but it was not included in the CERs derived in P-1530, except in a few instances. In most cases only costs for ships already delivered were used. Exceptions are ships of the SSBN-726 and CG-47 classes which are still being built. For these classes cost estimates were used. Although all the ships used have been authorized and funds appropriated for construction, these ships still have the potential for cost increases due to inflation, claims, cost growth, outfitting and post delivery costs.

METHODOLOGY

A. SELECTION OF CER CATEGORIES

Classes of U.S. Navy ships were aggregated into groups (categories) according to characteristics, functions, and missions to obtain a fit of mathematical curve forms to the data. Some ships did not fit well in their logical category based on these criteria; thus other criteria of hull design, machinery arrangement, and similarity of construction were used to categorize these ships. Examples are the amphibious assault ships (LHAs and LPHs), which are grouped with aircraft carriers vice amphibious ships, and amphibious cargo ships (LKAs), which are included with underway replenishment ships vice amphibious ships.

Nuclear powered ships were separated from non-nuclear powered ships of the same type and escort ships (cruisers, destroyers, and frigates) equipped with missiles were separated from non-missile-equipped escorts. The AEGIS cruisers were placed in a category by themselves because of their uniqueness. The number of ships in a class varied from one to 46. Each class represents one data point. In this paper 60 ship classes were organized into 12 CER categories.

1. Aircraft and helicopter carriers (CV, LHA, LPH)
2. Nuclear powered aircraft carriers (CVN)
3. Nuclear powered attack submarines (SSN)
4. Diesel powered submarines (SS)
5. Fleet ballistic missile submarines (SSBN)
6. Destroyers, frigates, and patrol combatants (DD, FF, PG)
7. Guided missile cruisers, destroyers, and frigates (CG, DDG, FFG).

8. Aegis cruisers (CG)
9. Guided missile cruisers (nuclear powered) (CGN)
10. Amphibious ships (LST, LSD, LPD, LCC)
11. Underway replenishment ships (AE, AF, AFS, AO, AOE, AOR, LKA[1])
12. Destroyer and submarine tenders (AD, AS)

These 12 categories are essentially the same as those in P-1530 except that the categories of mine warfare ships, tugs and salvage vessels, and single unit classes were omitted in this paper, and fleet ballistic missile submarines were added.

B. DATA SOURCES AND THEIR USE

The cost data were extracted from four Naval Sea Systems Command (NAVSEA) sources. For the period fiscal years 1952-1969, a report entitled Estimated Cost to Build or Convert Naval Ships [Reference 2] was used. This report provided by program year a total end cost for each ship by hull number including outfitting and post delivery costs. This end cost does not identify the year funds were appropriated, and it was assumed to be the program year. A single deflator for the program year was used to convert to FY 1983 dollars. Using a single deflator may overstate the cost of a ship in FY 1983 dollars, since some costs associated with construction between fiscal years 1952 and 1970 were appropriated in years subsequent to the program year. This possible overstatement of cost is believed to be small, because of the low rate of inflation during the early part of this period of time.

For the period FY 1969-1981 cost data were obtained from NAVSEA report Shipbuilding and Conversion, Navy, Shipbuilding Status Report as of December 1981 [Reference 3]. This report

[1]LKA ships included here because of the similarity in construction to AE and AF ships.

incorporates changes in NAVSEA accounting procedures. It displays cost information by program year for each ship by hull number. The cost for each ship is presented by major cost category code as defined in NAVSEA Instruction 7302.1 dated 6 October 1977. A major difference in the costs displayed in these two NAVSEA reports is in the accounting of outfitting and post delivery costs and what is included in the "Total End Cost." In reference 2 both outfitting and post delivery costs are included in "Total End Cost." In reference 3 neither outfitting nor post delivery costs are included in "Total End Cost," but, they are added to "Total End Cost" to produce a new cost term called "Grand Total Hull."[1] Both cost terms include all the elements of cost incurred to build a ship.

In reference 3 outfitting and post delivery costs are displayed for each year in which these funds were appropriated. Other cost category items funded in a fiscal year other than the year in which the ship was authorized and funds appropriated for construction are advance procurement, cost growth, escalation, and claims. To reflect properly the total cost of a ship in FY 1983 dollars that had funds in any of these cost categories, the deflator for the year in which the item was appropriated was applied. Before this last step was possible, the amount funded by year for each cost category was identified. Reference 3 provides this level of detail for outfitting and post delivery, but not for advance procurement, cost growth, escalation, and claims.

Identification of the amount of funds appropriated by fiscal year for each of these categories was accomplished through extracting data from NAVSEA status sheets entitled Shipbuilding and Conversion, Navy, Program Years 1962-1982 [Reference 4] and

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[1]Beginning in the mid 1970s outfitting and post delivery costs have been budgeted as a separate line item in the Shipbuilding and Conversion, Navy appropriation. The costs for outfitting and post delivery frequently appear in the program in more than one fiscal year.

Derivation of Cost Growth/Escalation, Etc., [Reference 5]. For example, in reference 4 the amount of advance procurement is displayed by fiscal year for a ship or a block of ships where several ships of the same class were funded in the same fiscal year. In this latter case, reference 3 was used to identify the amount of advance procurement allocated to each ship.

For the categories cost growth, escalation, and claims that were funded during FY 1972-1983, the amount funded is displayed in reference 4 as a single entry. However, reference 5 identifies the amount by fiscal year for each of these cost categories except for the period FY 1972-1975. The amount funded for these three cost categories for these four fiscal years is displayed as a single number. In order to estimate the cost of cost growth, escalation, and claims for these four years in FY 1983 dollars, an average deflator (43.5992) was derived from appropriate SCN OSD indices.

To summarize the use of references 3, 4 and 5 and to demonstrate the calculation of FY 1983 dollars, the following example using the USS Eisenhower (CVN-69) is displayed.

Ships are funded under the full funding concept whereby the Navy budgets and the Congress appropriates funds to fully finance the construction of a ship in the year of authorization, except for advance procurement, claims, outfitting, and post delivery. In the USS Eisenhower example the program year line represents the amount estimated to fully fund the ship in FY 1970 dollars. Advance procurement was provided in each of the two previous years. During the period FY 1972-1979 almost $221 million in then-year dollars were required to pay for unbudgeted escalation and cost growth, and claims. To accurately translate then-year dollars to FY 1983 dollars the appropriate deflator corresponding to each fiscal year in which funds were appropriated must be applied. This application of a number of deflators is especially important for ships

authorized and funded from the late 1960s to the present time due to the inflationary effects of the economy.

Table 1. USS EISENHOWER (CVN-69) PROCUREMENT COSTS
(Dollars in Thousands)

Cost Category	FY[a]	TOA Then Year $	Deflator	TOA FY 1983 $	Reference Source
Program Year Procurement[b]	70	388,361	28.8151	1,347,769	3,4
Advance Procurement	68	48,523	23.9695	202,436	4
	69	82,400	25.8534	318,720	4
Cost Growth/Escalation/Claims	72-75	182,195	43.5992	417,886	5
Cost Growth	76	13,954	54.6575	25,530	5
Claims/Escalation	77	11,349	61.7250	18,386	5
Claims	79	13,298	74.4161	17,870	5
Outfitting	76	4,676	54.6575	8,555	3
	7T	698	60.2517	1,158	3
	77	4,430	61.7250	7,177	3
	78	471	67.9456	693	3
Post Delivery	78	13,479	67.9456	19,838	3,4
Total		763,834		2,386,018	

[a]Fiscal year in which the funds were appropriated.

[b]This is the amount appropriated in the year the ship was authorized. The TOA amount in reference 4 is the same as the Total Net Procurement entry in reference 3.

C. NORMALIZATION OF THE DATA

The costs to procure ships were normalized to constant FY 1983 dollars. For an example of this process see Table 1. Other factors affecting cost that could have been normalized are lead ship costs, the number of ships built serially, and the differences in shipyards. These were not done for the following reasons.

Lead ship costs were included in the data to derive the CERs because the CERs are intended to estimate the cost of

groups of Soviet and U.S. ships, which include both lead ships and follow ships. Had the purpose been to derive CERs to estimate the cost of the next U.S. ship of a specific class, the normalization for lead ship cost would have been appropriate.

IDA Paper P-1530 examined the effects of building ships serially and concluded that there is essentially no learning curve in most Navy ship construction (if the lead ship is not included). Figures 2 and 3 of P-1530 illustrate this conclusion. The lack of learning in ship construction allows a single point representing the average ship procurement cost to suffice in the CER derivation.

There may be variations in cost that can be attributed to differences in shipyards. These differences can result from geographic location, public versus private shipyards, and other more subtle factors. The most significant difference in cost has been between ships of the same class that were constructed in public and private shipyards. Large variations in cost were the exception rather than the rule. Navy ships have not been constructed in public shipyards since 1968, thus this difference is no longer applicable. One would reasonably expect to find similar differences among Soviet shipyards, thus normalization for shipyard differences was not considered appropriate.

Other factors influencing the cost of ships are ship program, method of contracting, and scheduling. No attempt is made to make adjustments for these factors.

D. COST ESTIMATING RELATIONSHIPS

1. Cost-Displacement Relationship

Three equations of curve fit forms were used to test the cost-displacement relationship for each of the 12 groups of ships. The three equations and their function forms that were

used are:

(1) $C = A + BD$ Linear Function

(2) $C = Ae^{BD}$ Exponential Function

(3) $C = AD^{B}$ Power Function

Where:

C = Average ship procurement cost in millions of dollars

A = A constant

B = A constant

D = Ship full load displacement in thousands of long tons.

The method least squares was used to fit each equation to the data. On occasions when equation (1), the linear form, resulted in a negative value of A, it was disallowed as it implies that a ship of finite displacement could be built for zero cost. Whenever this condition happened a simpler linear equation ($C = BD$), which passes through the origin, was used. In this paper when either equations (2) or (3) yielded the least error it was also presented to describe the cost-displacement relationship.

2. Cost-Displacement IOC Relationships

As mentioned in the introduction, an IOC-dependent term was included to account for the cost increase from one generation of ships to the next. The data were transformed into logarithmic expressions of the variables and a linear multiple regression analysis performed. The linear multiple regression equation that results from converting the logarithmic equation to a power form is as follows:

$$C = AD^{B}T^{(IOC-81)}$$

Where:

C = Average ship procurement cost in millions of dollars

A = A constant
B = A constant
T = A constant

The value of the constant differs for each group of ships regressed.

D = Ship full load displacement in thousands of long tons

(IOC-81) = Last two digits of the ship class IOC minus 81, the reference year for the time-dependent term.

The results of this regression analysis yielded spurious results and are not displayed in this document.

RESULTS

Both the linear form of CER, and the form when the least error CER is not linear, are displayed in Table 2 along with other selected informational data. The differences (a) between observed and estimated costs for each ship class, and (b) between the total observed cost and the corresponding total CER estimated cost for each major grouping of ships, are also presented in Table 2. In all cases the two total costs for the major groupings are quite close, because the positive and negative differences of the estimated costs relative to the observed costs for each individual class of ship tend to cancel out within the major groupings. The results for each group of ships regressed are discussed in the following sections in the same order as they appear in Table 2.

A. AIRCRAFT AND HELICOPTER CARRIERS

In this category conventional carriers (CVs) are combined with the LHA and LPH amphibious assault ships. This combination was necessitated by the three classes of CVs (CV-59, 63, 67) having about the same full load displacement. The power form of cost-weight relationship best fits the data $\left(C = 12.3D^{1.122}\right)$. The category error was 1.3 percent and the average ship class absolute error was 5.9 percent. Figure 1 displays both the power form curve and the linear relationship. The linear equation produced a negative intercept, therefore a simpler linear equation which passes through the origin (C = 20.66D) was fitted. The category error using this equation was 3.7 percent and the average ship class absolute error was 8.5

Table 2. SHIP COST ESTIMATING RELATIONSHIPS

(Cost is in Thousands of FY 1983 Dollars)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displacement-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Total Observed Cost by Class	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Least Error CER**	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Linear CER***
Aircraft and Helicopter Carriers															
CV	59	4	1955	79,650	1,491[a]	1,496	5,984	1,671.2	6,685	+11.7		1,645.6	6,582	+10.0	
	63	3	1961	80,300	1,832	1,753	5,259	1,686.5	5,060	-3.8		1,659.0	4,977	-5.4	
	67	1	1968	80,800	1,737	1,737	1,737	1,698.3	1,698	-2.2	$C = 12.3D^{1.122}$	1,669.3	1,669	-3.9	C = 20.66D
LHA	1	5	1976	39,300	847.1	818.2	4,091	756.5	3,783	-7.5		811.9	4,060	-0.8	
LPH	2	7	1961	18,300	336.1	308.3	2,158	320.9	2,246	+4.1		378.1	2,647	+22.6	
Total							19,229		19,472	+1.3			19,935	+3.7	
CVN	65	1	1961	91,000	3,065	3,065	3,065	2,604	2,604	-15.0	$C = 670 + 12.3D^{1.122}$	2,610	2,610	-14.8	C = 730 + 20.66D
	68	2	1975	94,400	2,974	2,680	5,360	2,686	5,372	+0.2		2,680	5,360	0	
Total							8,425		7,976	-5.3			7,970	-5.4	
Attack Submarines															
SSN	578	4	1957	2,860	484.9	338.3	1,353	335.8	1,343	-0.7					
	585	6	1959	3,500	478.6	356.7	2,140	364.8	2,189	+2.3					
	594[b]	14	1961	4,450	874.0	543.1	7,603	407.6	5,706	-24.9	C = 206 + 45.3D				
	637	37	1967	4,582	443.3[c]	421.3	15,588	413.8	15,311	-1.8					
	688	12	1976	6,927	853.1	518.2	6,218	520.1	6,241	+0.4					
Total							32,902		30,790	-6.4					
SS	576	1	1956	2,388	168.2	168.2	168	154.2	154	-8.3	C = 46 + 45.3D				
	580	3	1959	2,639	227.4	165.4	496	165.4	496	0					
Total							664		656	-2.1					
Fleet Ballistic Missile Submarines															
SSBN	598	5	1959	6,688	1,223.3	802.7	4,014	660.5	3,303	-17.7		626.6	3,133	-21.9	
	608	5	1961	7,880	1,004.5	710.4	3,552	724.8	3,624	+2.0	$C = 392e^{.078D}$	728.4	3,642	+2.5	C = 30 + 89.2D
	616	31	1963	8,220	1,029.1	609.8	18,904	744.3	23,073	+22.1		763.2	23,659	+25.2	
	726	7	1981	17,500	2,453.8	1,591.6	11,141	1,535.0	10,745	-3.6		1,591.0	11,137	0	
Total							37,611		40,745	+8.3			41,571	+10.5	
Destroyers, Frigates, and Patrol Combatants															
DD	931	18	1954	3,960	285.8	187.9	3,382	160.9	2,896	-14.4					
	963	30	1975	7,924	445.2	307.7	9,231	310.9	9,327	+1.0					
FF	1006/1021	13	1954	1,914	138.9	75.7	984	83.5	1,086	+10.3					
	1033	4	1959	1,750	70.2	67.5	270	77.3	309	+14.5	C = 11.1 + 37.8D				
	1037	2	1963	2,690	123.5	114.4	229	112.9	226	-1.3					
	1040	10	1964	3,344	173.0	148.5	1,485	137.6	1,376	-7.3					
	1052	46	1969	4,100	341.5	144.2	6,633	166.2	7,645	+15.3					
PG	84	17	1966	260	31.1[d]	24.6	418	21.0	357	-14.6					
Total							22,632		23,222	+2.6					

*LT = Long Tons.

**Least error CER is defined as the CER that has the least average ship class absolute error.

***Linear CER is displayed where the least error CER is another form.

Table 2. (Continued)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displace-ment-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Total Observed Cost by Class	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Least Error CER**	Estimated Cost	Total Estimated Cost by Class	Percent Difference	Linear CER***
Guided Missile Cruisers, Destroyers, and Frigates															
CG	16	9	1962	8,074	601.0	435.3	3,918	418.8	3,769	-3.8					
	26	9	1964	8,500	522.7	412.1	3,709	436.4	3,923	+5.9					
DDG	2	23	1960	4,500	343.1	255.9	5,886	271.5	6,245	+6.1	C = 86.1 + 41.2D				
	37[e]	10	1960	5,960	448.4	356.7	3,567	331.7	3,317	-7.0					
FFG	1	6	1966	3,600	234.4	187.6	1,126	234.4	1,406	+24.9					
	7	10	1977	3,605	630.9	279.9	2,799	234.6	2,346	-16.2					
Total							21,005		21,011	0					
AEGIS CG															
CG	47	7	1983	9,200	1,368.7	1,076.8	7,538	1,076.8	7,538	0	C = 698 + 41.2D				
Guided Missile Cruisers (Nuclear Powered)															
CGN	9	1	1961	17,100	2,232.6	2,232.6	2,233	a	-	-					
	25	1	1962	9,200	1,052.4	1,052.4	1,052	855.0	855	-18.7					
	35	1	1967	8,800	831.5	831.5	832	838.6	839	+0.8	C = 476 + 41.2D				
	36	2	1974	10,530	902.8	852.2	1,704	909.8	1,820	+6.8					
	38	4	1976	11,000	928.4	795.7	3,183	929.2	3,717	+16.8					
Total							9,004		7,231	+6.8					
Amphibious Ships															
LST	1171[f]	7	1957	7,804	162.4	98.4	689	95.2	666	-3.3		138.9	972	+41.2	
	1179	20	1969	8,400	282.4	112.2	2,244	103.2	2,064	-8.0		149.5	2,990	+33.2	
LSD	28	8	1954	12,000	220.1	153.6	1,229	167.8	1,342	+9.2		213.6	1,709	+39.1	
	36	5	1969	14,000	161.1	155.6	778	219.8	1,099	+41.3	$C = 33.2e^{.135D}$	249.2	1,246	+60.2	C = 17.8D
LPD	1	3	1962	14,651	308.7	290.5	872	240.0	720	-17.4		260.8	782	-10.2	
	4	11	1965	16,913	g	245.5	2,701	325.6	3,582	+32.6		295.7	3,249	-20.4	
LCC	19	2	1970	17,000	632.1[h]	490.3	981	329.5	659	-32.8		302.6	605	-38.3	
Total							9,494		10,132	+6.7			11,553	+21.7	
Underway Replenishment Ships															
AE	21	5	1956	17,450	138.4	117.8	589	139.1	696	+18.1		134.1	671	+13.8	
	26	8	1968	19,937	189.4[i]	180.8	1,446	147.5	1,180	-18.4		147.8	1,182	-18.3	
AF	58	2	1955	15,540	128.7[j]	128.9	258	133.0	266	+3.2		123.5	247	-4.2	
AFS	1	7	1963	16,049	160.5	140.7	985	134.6	942	-4.3		126.3	884	-10.2	
AO	143	6	1953	39,800	209.6	172.4	1,034	235.6	1,414	+36.7	$C = 92.2e^{.024D}$	257.8	1,547	+49.5	C = 37.4 + 5.54D
	177	3	1981	27,500	251.6	207.8	623	176.3	529	-15.2		189.7	569	-8.7	
AOE	1	4	1963	53,600	452.9	423.6	1,694	326.1	1,304	-23.0		334.2	1,337	-21.1	
AOR	1	7	1969	41,350	224.0	201.0	1,407	244.3	1,710	+21.5		266.4	1,865	+32.5	
LKA	113	5	1968	18,657	175.3	147.6	738	143.1	716	-3.0		140.7	704	-4.7	
Total							8,774		8,757	-0.2			9,006	+2.6	

*LT = Long Tons.

**Least error CER is defined as the CER that has the least average ship class absolute error.

***Linear CER is displayed where the least error CER is another form.

[a] CGN-9 was not included in deriving the CER, thus the CER is not applicable.

Table 2. (Continued)

Class	Lead Ship Hull No.	No. of Ships Costed	IOC	Full Load Displace-ment-LT*	Lead Ship Cost	Observed Ave. Cost of Ships by Class	Estimated Cost	Percent Difference	CER
Destroyer and Submarine Tender									
AD	37	2	1967	20,500	354.5	325.2			
	41	4	1980	20,500	391.5[k]	407.6			
AS	31	2	1962	19,819	351.4[l]	355.4	Data was too clustered to produce a reasonable CER.		
	33	2	1964	21,000	408.3	359.8			
	36	2	1970	23,493	324.2	286.1			
	39	3	1979	22,646	450.7	425.2			

*LT = Long Tons.

[a]Low lead ship cost is because of the four ships in this class, the first and third ships were built at Newport News and the second and fourth ships were built at the New York NSY. These latter ships were more costly than the lead ship built at Newport News.

[b]Data includes the Thresher (SSN-593) which was lost during sea trials. This class was omitted from the derivation of the CER.

[c]The lead ship was built by Electric Boat, however, the first four follow-on submarines were built by four different shipyards, (two NSYs and two PSYs) all at a higher cost than the lead ship.

[d]The first eight ships in this class were built by the same shipyard. Follow ships three and four were about 80 percent more costly than the lead ship. The remainder of the ships were built at about 56 to 74 percent of lead ship cost by two builders.

[e]The DDG-37 class was originally classified as the DLG-6 class.

[f]Although the LST-1171 is the lowest hull number of this class, the class is named for the Suffolk County (LST-1173) which is designated the lead ship of the class.

[g]The first three ships of this class were authorized and funded in the same year. The cost data available did not identify costs by hull number; therefore, the cost for the lead ship cannot be determined.

[h]The LCC-19 was built by the Philadelphia NSY and the follow ship by Newport News at about 55 percent of the lead ship cost.

[i]Ships of the AE-26 class were authorized and funded at a rate of two per year, both built by the same builder. It appears that the cost of the first two ships were about equally divided; therefore, a typical lead/follow ship cost relationship does not exist.

[j]Same situation as for the AE-26 class.

[k]Two of the three follow ships cost more to build than the lead ship.

[l]The two ships of this class were built by two shipyards with the follow ship more costly than the lead ship.

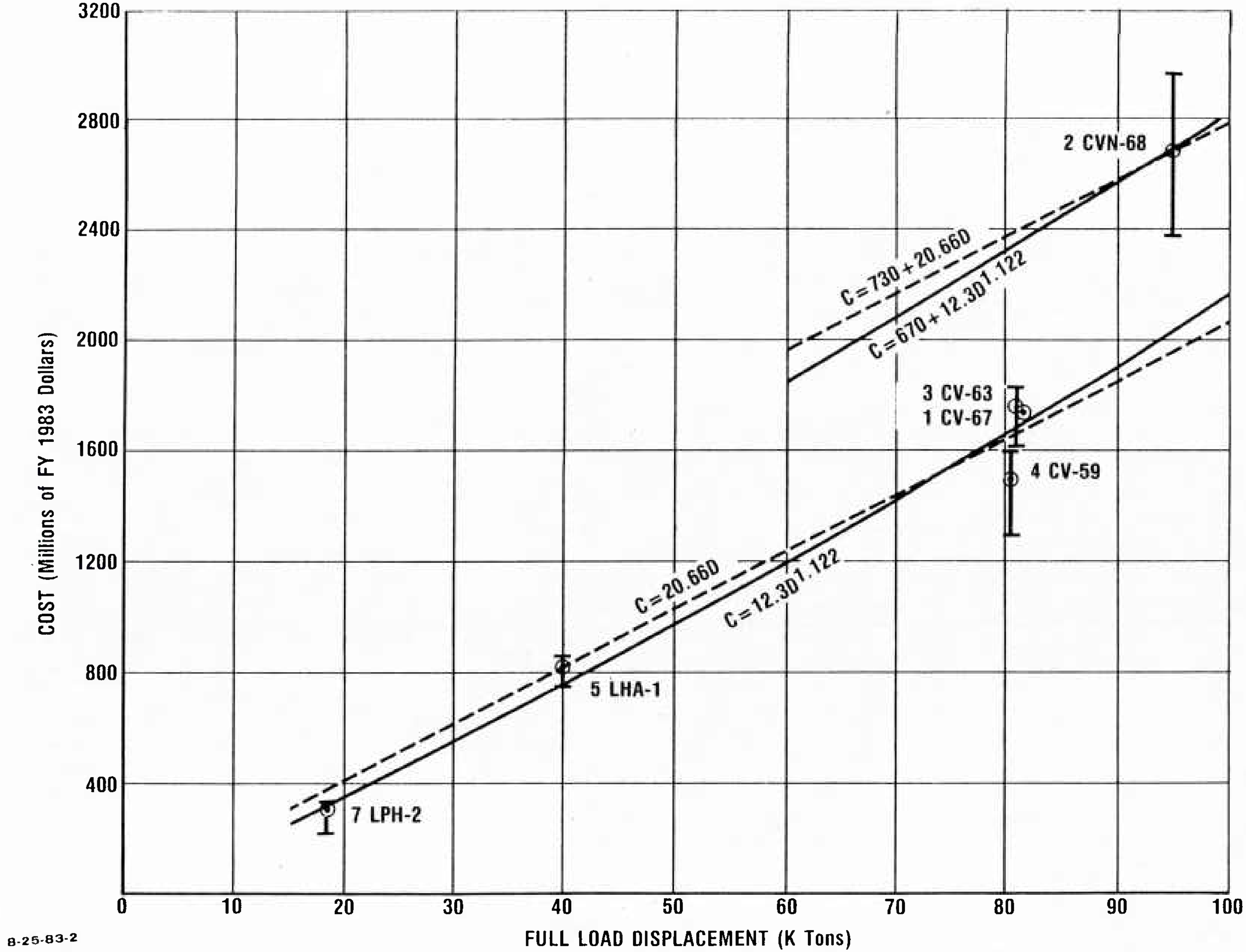

Figure 1. COST VERSUS WEIGHT CURVES FOR AIRCRAFT AND HELICOPTER CARRIER

percent. A comparison of the two curves described by these equations can be observed in Figures 2 and 3.

There are only two classes of U.S. nuclear powered aircraft carriers (CVN-65 and 68) with full load displacements that are proximate. The CVN-65 is a one-of-a-kind ship and the first CVN ever built. Thus using the CVN-65 cost as a data point is unwarranted. This leaves a single data point for the CVN-68 class from which to develop a CER. One alternative is to simply draw a line from the origin through the CVN-68 data point. This would imply that one could build small nuclear powered air capable ships for a small increase in cost over that of a conventional powered ship of the same size.

A recently completed IDA study[1] indicates that the increased cost for nuclear propulsion over conventional propulsion for U.S. aircraft carriers may be much closer to a constant. The cost of nuclear power in relation to ship weight is very likely some form of a step function; however, over some range of weight for a given type of ship it is probably close to a constant. The addition of nuclear power to any ship is a complex operation; therefore, an attempt to estimate the cost of nuclear power from one type of ship to another is likely to yield questionable results. IDA Draft Report R-265 identified seven comparisons of procurement cost ratios between nuclear and conventionally powered aircraft carriers displacing 80,000-90,000 tons. The ratios of the cost of nuclear power to conventional power ranged from 1.37 to 1.59 (an average of 1.46). Similar comparisons for carriers displacing about 60,000 tons yielded ratios ranging from 1.64 to 1.75. These data suggest that a constant incremental cost for nuclear power for aircraft carriers ranging from 60,000-90,000 tons is reasonable. This

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[1]Herschel Kanter, Jeffrey Grotte, William J.E. Shafer, and Debra Angello, Surface Combatant Ships: Issues in Nuclear vs Non-Nuclear Surface Ships (U), IDA Report R-265, Final Draft, April 1982, SECRET.

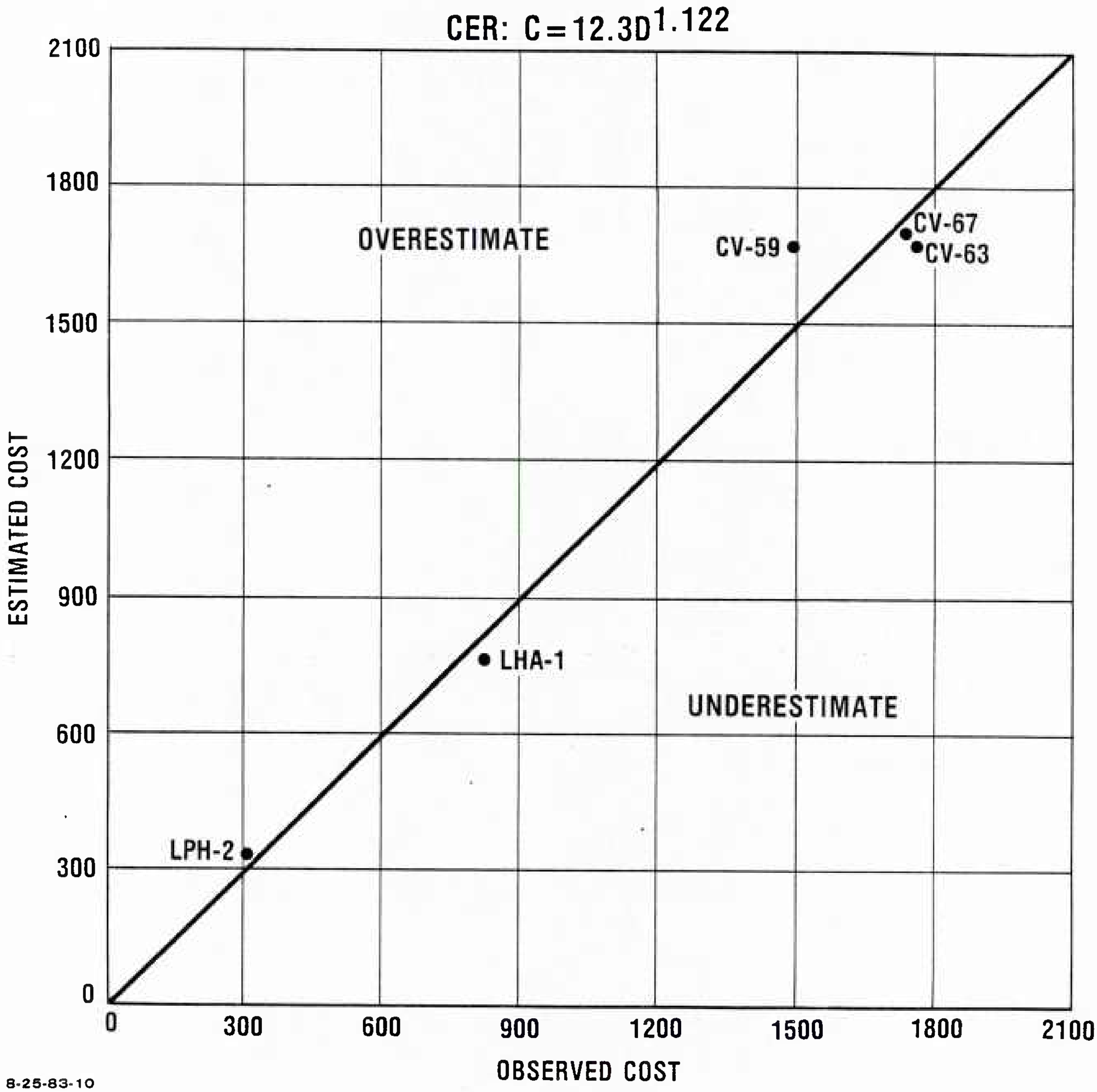

Figure 2. ESTIMATED COST OF AIRCRAFT AND HELICOPTER CARRIERS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A POWER FORM EQUATION

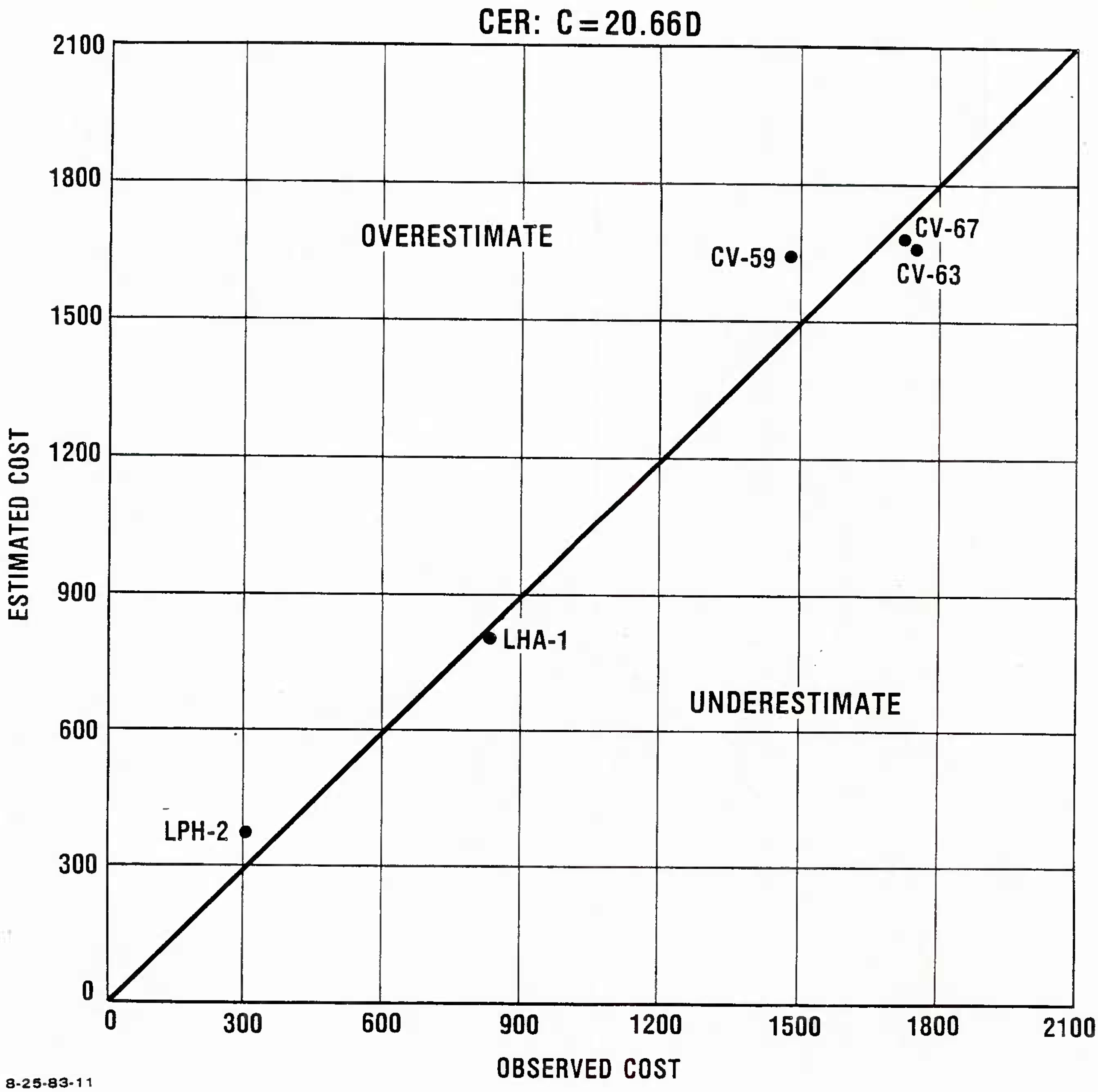

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Figure 3. ESTIMATED COST OF AIRCRAFT AND HELICOPTER CARRIERS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

incremental cost for nuclear power was estimated to be $670 million based on the difference between the cost of the CVN-68 class and the non-linear equation of Figure 1 and $730 million based on the linear equation. The non-linear equation that describes the CVN cost estimate curve is $C = 670 + 12.3D^{1.122}$ and the linear one is $C = 730 + 20.66D$.

The reader is cautioned in the case of these CERs. The CERs are based on LPH and LHA data at the smaller displacements and CV/CVN data for displacement values of about 80,000 tons and above. The curve could lead to an under estimation of the cost of building CVs having displacements in the range of 40-60,000 tons. Amphibious assault ships which can support helicopters of VSTOL aircraft, do not possess catapults, angle decks, and the extensive avionics shop and support facilities that would be required of a small CV capable of operating air superiority aircraft.

B. ATTACK SUBMARINES

This category is separated into nuclear powered (SSN) and conventional powered (SS) submarines. Five classes of SSNs have been authorized and funded since 1957. The latest class, the SSN-688 class, is still in the construction phase. Twelve of these SSNs have been delivered and their cost is used in the development of the SSN CER. The cost/displacement relationship for four classes of SSN is linear. One class, the SS-594 class, does not fit on this linear curve. The lead ship of this class was the Thresher (SSN-593) which was lost during sea trials. That loss delayed the building program and concentrated attention on submarine safety. Both were costly and added significantly to the average cost of this class. The average cost of the SSN-594 class was greater than the twelve submarines of the larger, more complex SSN-688 class. Because of these unusual circumstances associated with the SSN-594 class, it was eliminated from the CER calculation. The CER derived from using

cost-weight data for the four classes of SSNs is $C = 206 + 45.3D$, which is displayed in Figure 4. The goodness of fit is shown in Figure 5. Even when the SSN-594 is included, the total error for the U.S. SSN category is only 6.4 percent and the average ship class absolute error is 6.0 percent.

As only four conventionally powered attack submarines (the SS-576 and the three ships of the SS-580 class) have been authorized and funded since 1956 there are few data points from which to develop a CER. The other diesel submarines produced in the U.S. (SS-572 and SSG-574) were of such special configuration as to not represent proper members of the category. In this situation the same approach as for aircraft carriers was assumed i.e., that the difference between nuclear and non-nuclear vessels was essentially constant and independent of displacement. Forcing the CER to satisfy the cost for the SS-580 class yields the result: $C = 46 + 45.3D$. The result is a category error of 2 percent for the cost of U.S. diesel submarines and an average ship class absolute error of 4.2 percent.

C. FLEET BALLISTIC MISSILE SUBMARINES (SSBNs)

For the first three classes of SSBNs each successive class grew in size, yet had a smaller average cost per ship (See Table 2). Accordingly, the CER for SSBNs is derived from essentially two data points -- one representing the average of the first three classes of SSBNs and the other being for the Ohio class SSBNs.[1] The exponential CER for SSBNs is $C = 392e^{.078D}$. A linear equation also provides a good fit to the data and essentially parallels the exponential curve except at the lower and upper ends. Figure 6 displays both curves. Data points for the five classes of SSNs are also plotted on Figure 6 although they are not used to derive the SSBN CER. Most of the SSN data

[1]The cost of the first seven Trident submarines is an estimate based on the TOA appropriated and budgeted as of December 1981.

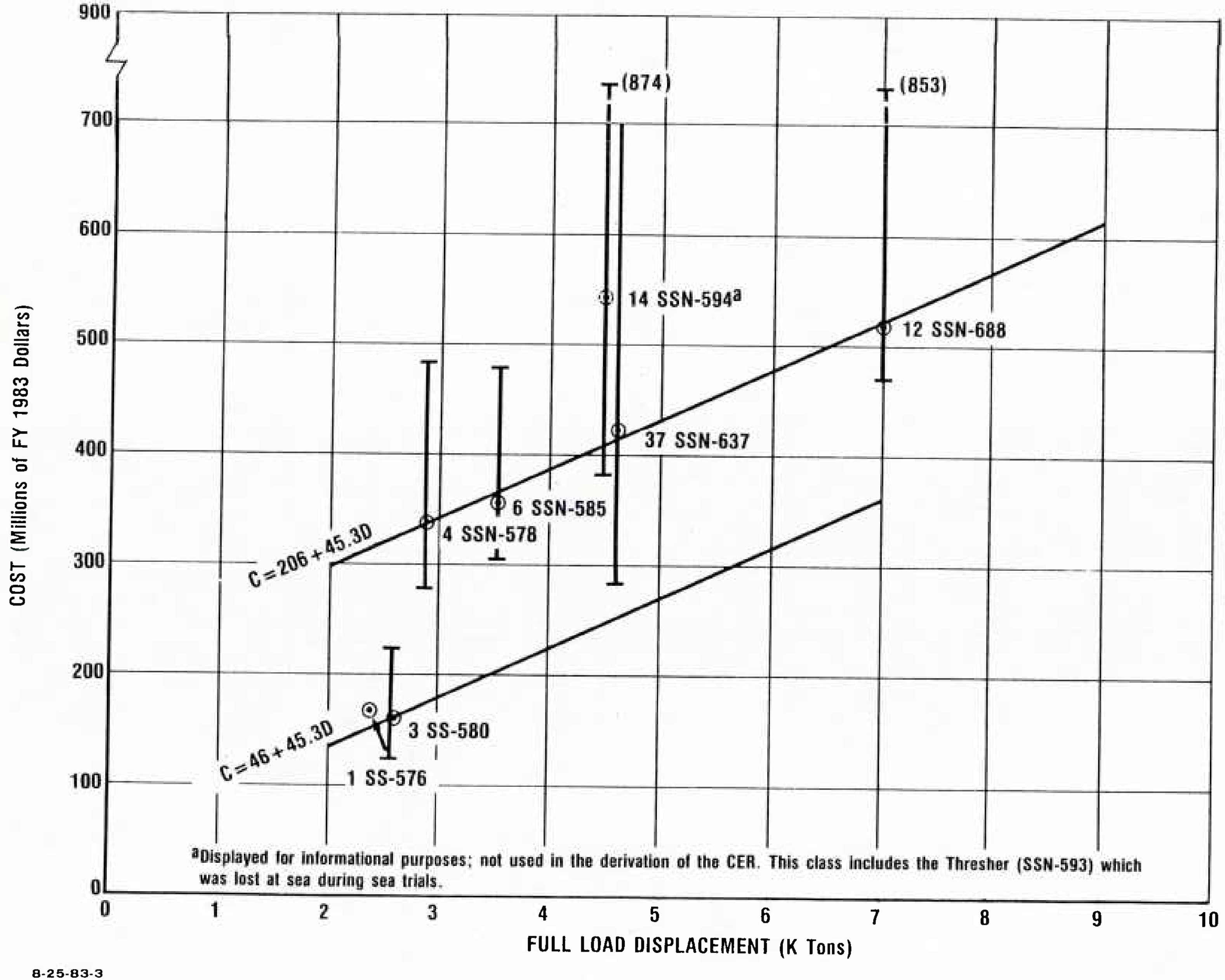

Figure 4. COST VERSUS WEIGHT CURVES FOR ATTACK SUBMARINES (NUCLEAR AND CONVENTIONAL POWERED)

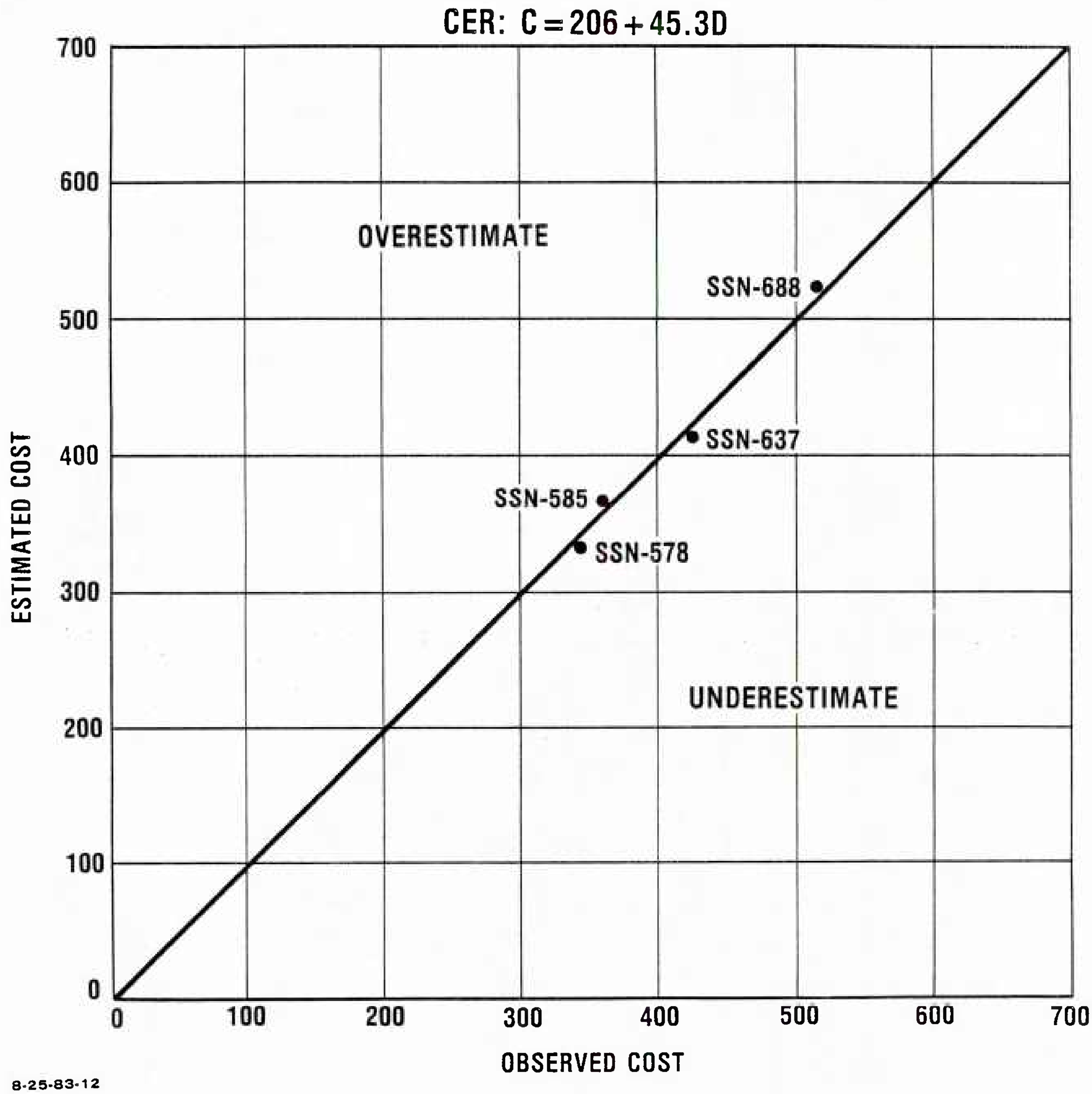

Figure 5. ESTIMATED COST OF ATTACK SUBMARINES BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

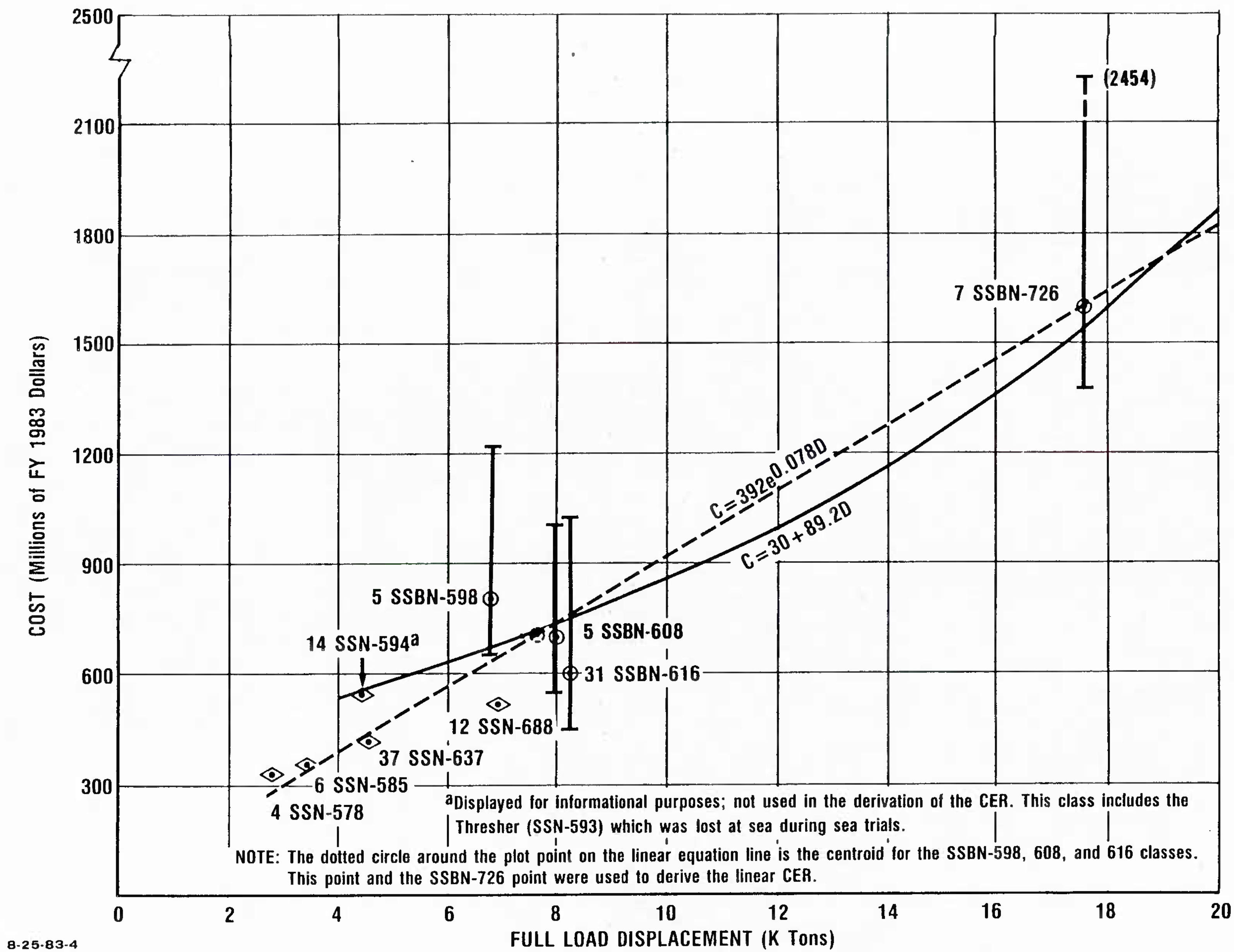

Figure 6. COST VERSUS WEIGHT CURVES FOR FLEET BALLISTIC MISSILE SUBMARINES

points plot close to the linear CER. The percent difference using the exponential CER is 8.3 percent for the category error and 11.4 percent for the average ship class absolute error. Using the linear CER the category error is 10.5 percent and the average ship class absolute error is 13.1 percent. A comparison of the curve fit of both equations is portrayed in Figures 7 and 8.

D. DESTROYERS, FRIGATES, AND PATROL COMBATANTS

Patrol combatants (PGs) were included with destroyers and frigates to make one category. A linear equation that best fits the data is $C = 11.1 + 37.8D$. This equation yields a category error of 2.6 percent and an average ship class absolute error of 9.8 percent. Figure 9 displays the DD, FF, and PG curve, and the curve fit is depicted in Figure 10.

E. GUIDED MISSILE CRUISERS, DESTROYERS, AND FRIGATES

The curve resulting from applying the CER for this category of ships is also plotted in Figure 9. This category includes the CGs, DDGs, and FFGs, all equipped with guided missiles. These ships are sometimes referred to as "G" ships. The equation that provides the best fit to the data is $C = 86.1 + 41.2D$. The error for this category is essentially zero; however, the average class absolute error is 10.7 percent. The CER curve for this category nearly parallels that of the DD, FF, and PG category. This parallelism indicates that the incremental cost between missile ship and non-missile ship of equal displacement is about $85-100 million. The curve fit for the "G" ships is displayed in Figure 11.

The CG-47 (Aegis cruisers) are conventionally powered ships now under construction. It is assumed that the slope of the CER curve for Aegis CG category ships would be the same as for the FFG, DDG, and CG category. The average cost of the

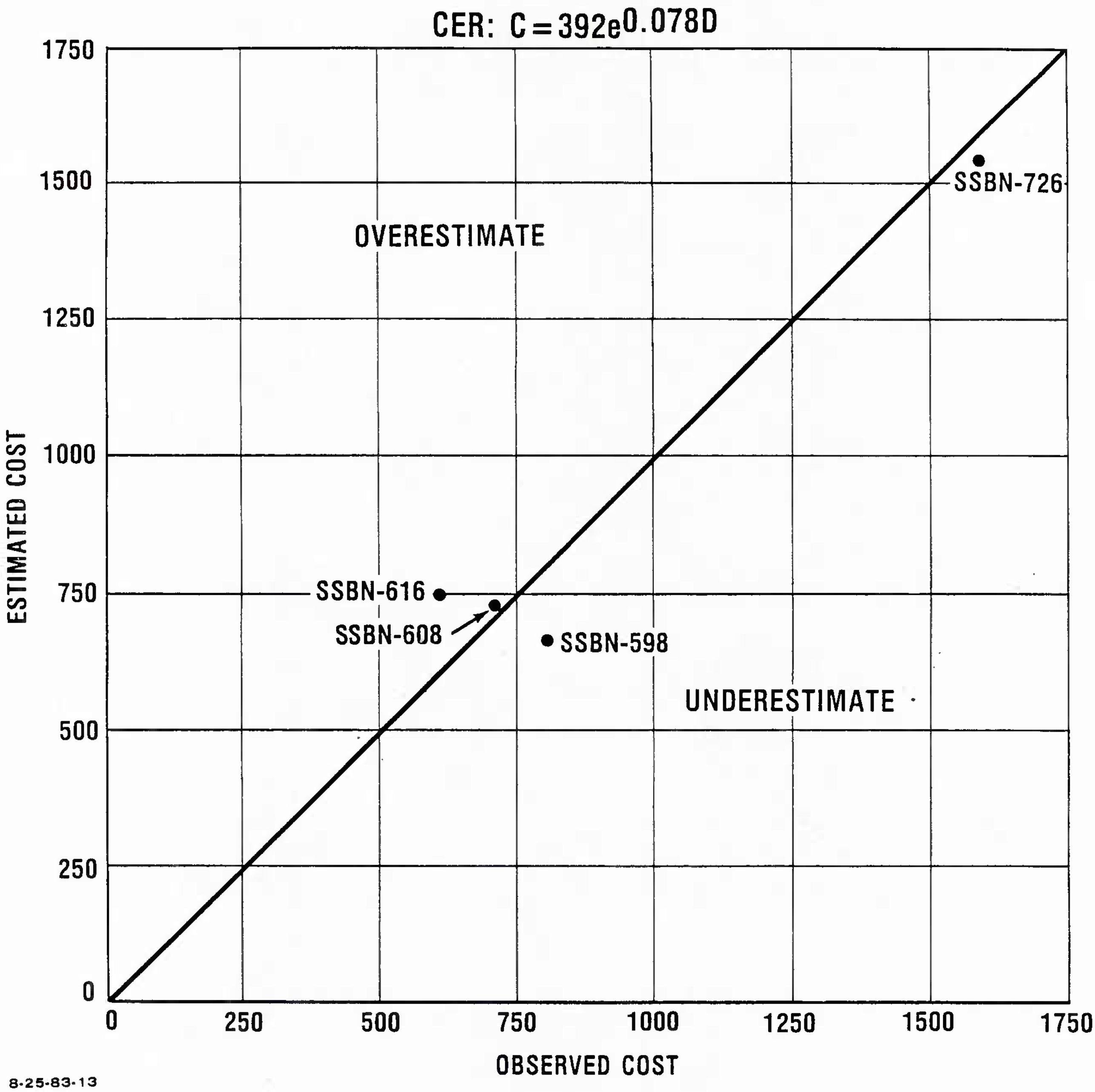

Figure 7. ESTIMATED COST OF FLEET BALLISTIC MISSILE SUBMARINES BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING AN EXPONENTIAL EQUATION

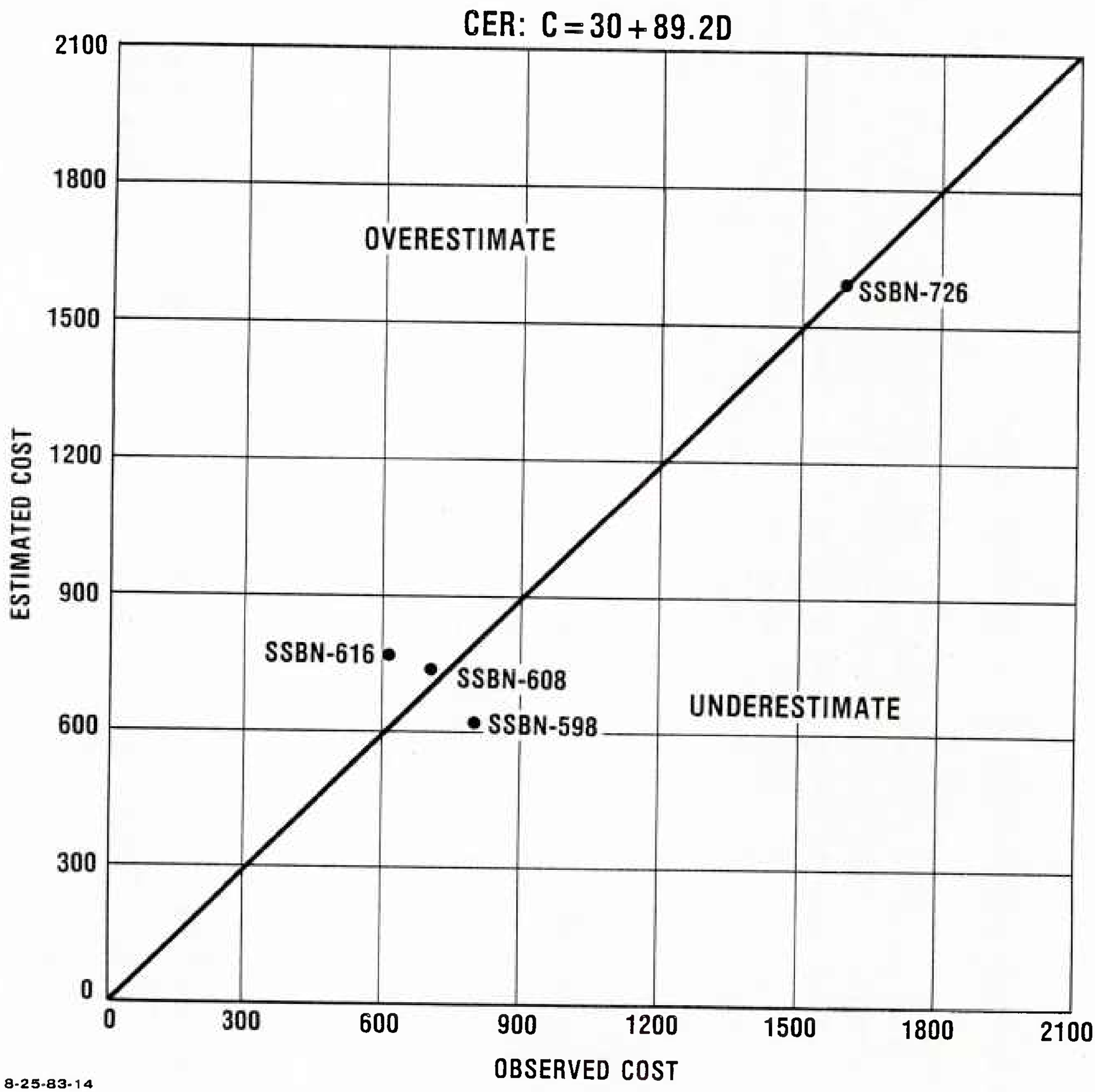

Figure 8. ESTIMATED COST OF FLEET BALLISTIC MISSILE SUBMARINES BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

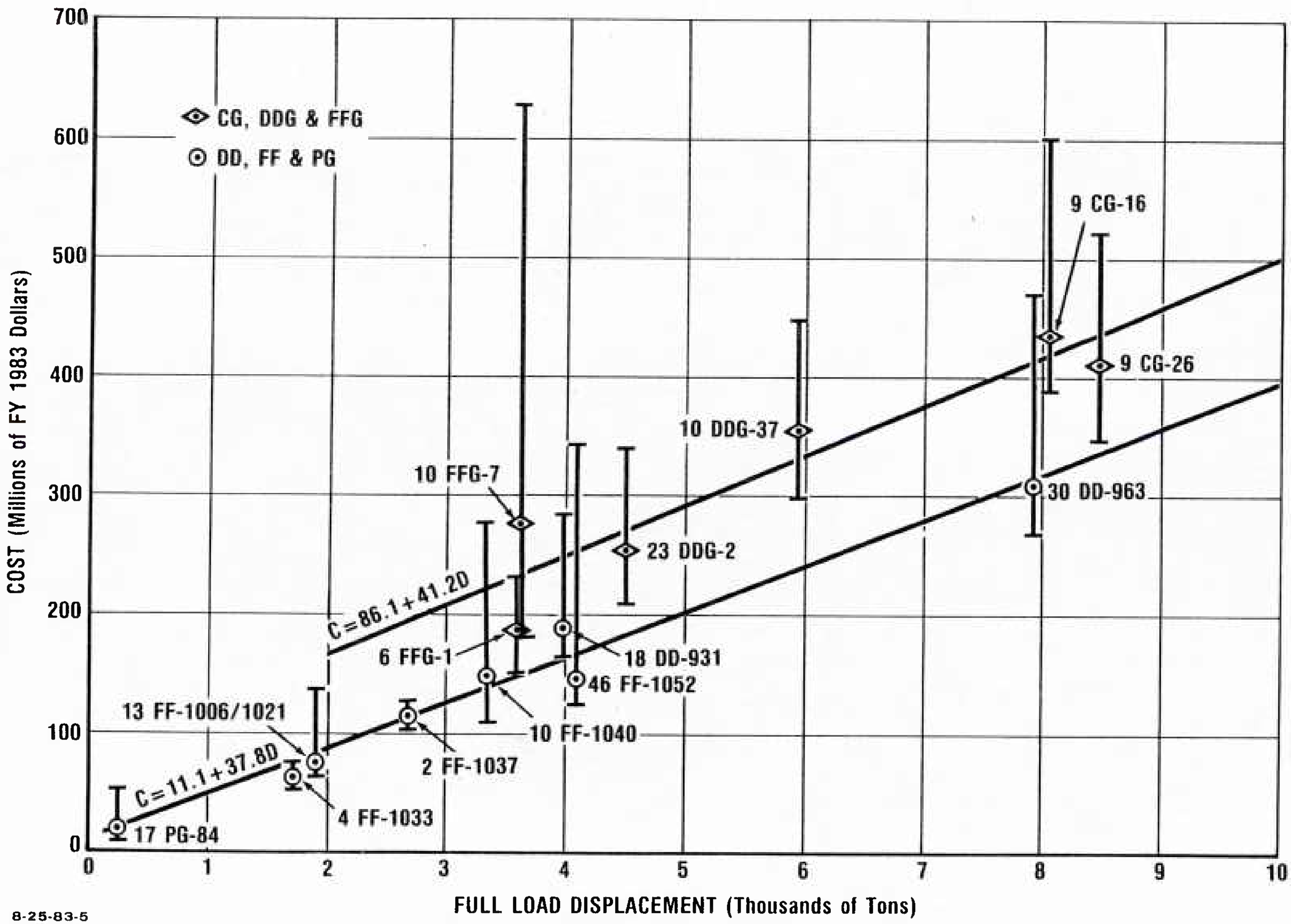

Figure 9. COST VERSUS WEIGHT CURVES FOR CRUISERS, DESTROYERS, FRIGATES AND PATROL COMBATANTS

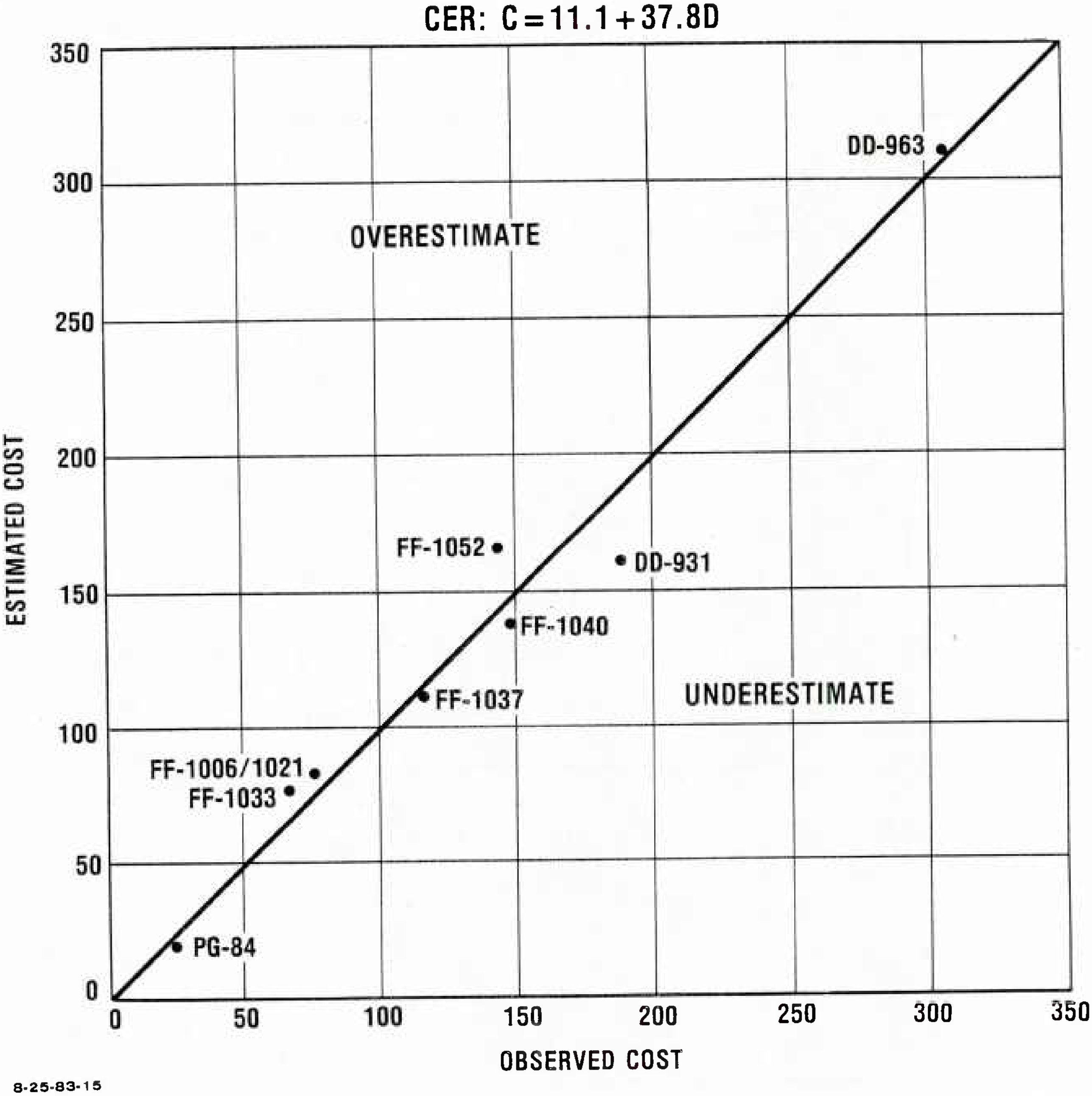

Figure 10. ESTIMATED COST OF DESTROYERS, FRIGATES AND PATROL COMBATANTS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

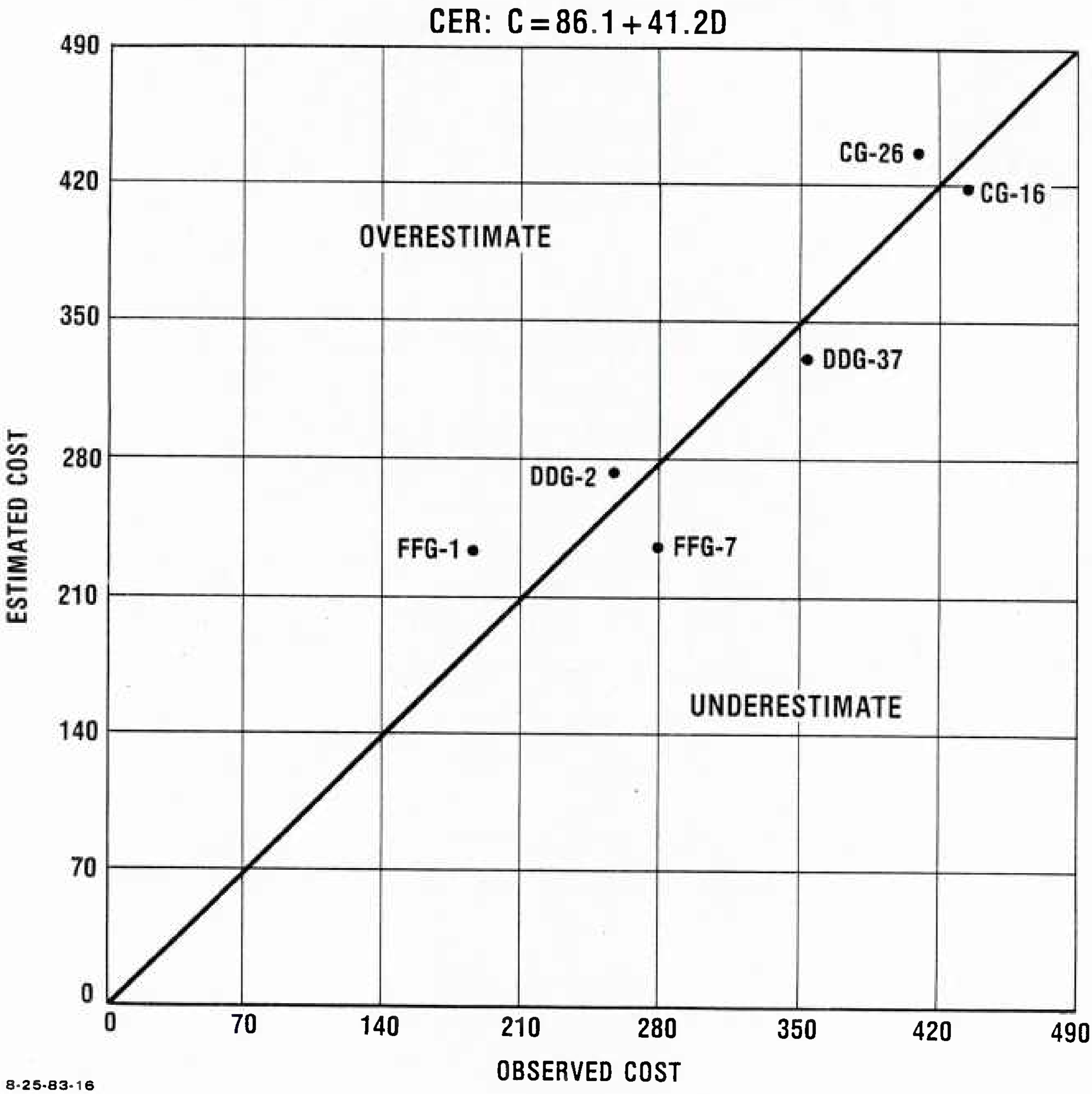

Figure 11. ESTIMATED COST OF GUIDED MISSILE CRUISERS, DESTROYERS, AND FRIGATES BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

first seven Aegis cruisers is $1,077 million with each ship having full load displacement of about 9,200 long tons. Thus the cost-weight ratio for this class of ship greatly exceeds that of similar-hull vessels constructed previously. The resulting CER is C = 698 + 41.2D. The reader is cautioned that this CER is based on the same slope as the FFG, DDG, and CG category and is based on a single data point.

F. GUIDED MISSILE CRUISERS (NUCLEAR POWERED)

This category includes nine nuclear powered cruisers built for the U.S. Navy. For eight of the nine the spread in displacement is only 2,200 tons. The remaining cruiser, CGN-9, was the first nuclear powered cruiser constructed and it underwent major design changes during construction. It is omitted from the derivation of the CGN CER for that reason. Since the remaining four classes of CGN have a narrow displacement and cost range that does not lend itself to deriving a valid CER, the incremental cost of CGNs above that for the FFG, DDG, CG equation was calculated as $390 million and applied to that equation. The same slope as the CER curve for FFG, DDG, CG was assumed. Figure 12 displays the resulting CGN equation C = 476 + 41.2D. This equation produced a category error of 6.8 percent and an average ship class absolute error of 10.8 percent. Figure 13 presents the curve fit of this equation.

G. AMPHIBIOUS SHIPS

The type of ships comprising this category are the LST, LSD, LPD, and LCC. The LPH and LHA amphibious assault ships were included with aircraft carriers and the amphibious cargo ships (LKA) are included in the underway replenishment ships category, because of their similarity in construction to Ammunition ships (AEs) and Refrigerated Stores ships (AFs).

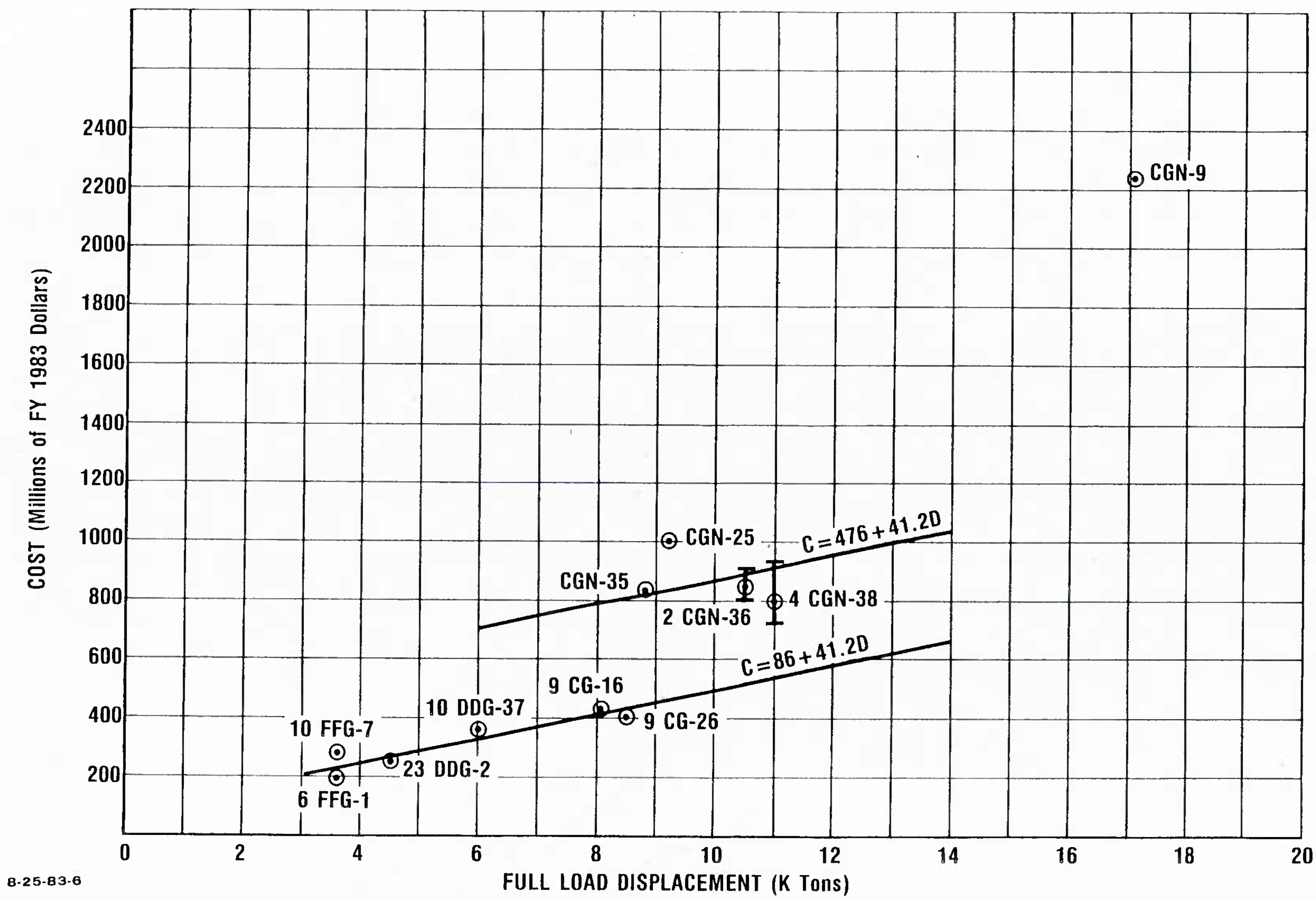

Figure 12. COST VERSUS WEIGHT CURVE FOR NUCLEAR POWERED CRUISERS

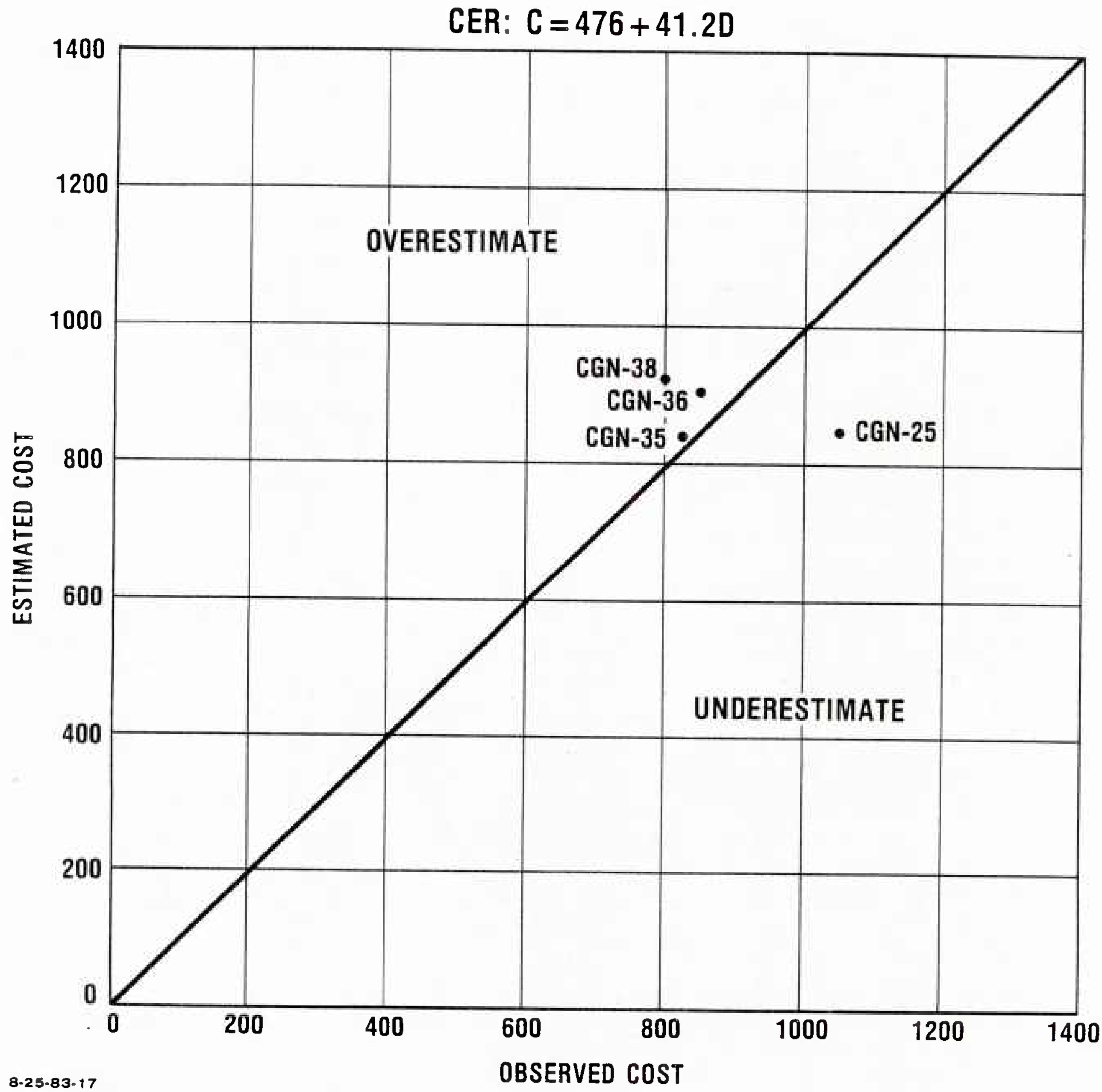

Figure 13. ESTIMATED COST OF GUIDED MISSILE CRUISERS (NUCLEAR POWERED) BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

From Figure 14 it is apparent that a good curve fit cannot be obtained from the data points. There are three conditions that prevent a good curve fit. First, the ships of the LSD-36 class which displace about 2,000 tons more than ships in the LSD-28 class, were constructed about twelve years after those in the LSD-28 class at about the same cost in constant dollars. Second, a somewhat similar situation exists with respect to the LPD-1 and LPD-4 classes. The three ships of the LPD-1 class were constructed by the New York Naval Shipyard. This same shipyard constructed the first three ships of the LPD-4 class, which displace about 2,300 tons more than ships of the LPD-1 class. These three ships had an average construction cost of $329 million; whereas, the last nine ships of the LPD-4 class were built in three private shipyards at an average cost of $218 million. Thus the larger LPDs were constructed at a lower average cost than were the smaller LPDs.

The third condition is the construction of the two LCCs. The lead ship was built in a Naval shipyard at a cost factor of 1.8 times the cost of the second LCC, which was built in a private shipyard. The resulting high average cost combined with a full load displacement that is about the same as the LPD-4 class produces very divergent data points. From the three curve fits attempted, an exponential equation $C = 33.2e^{.135D}$ was selected for this CER. The cost estimate error for this category is 6.7 percent. The average ship class absolute error is 20.7 percent.

The CER results obtained using a simple linear equation ($C = 17.8D$) produced an estimate error for this category of 21.7 percent and an average ship class absolute error of 34.7 percent. The goodness of curve fit to the data is displayed in Figures 15 and 16.

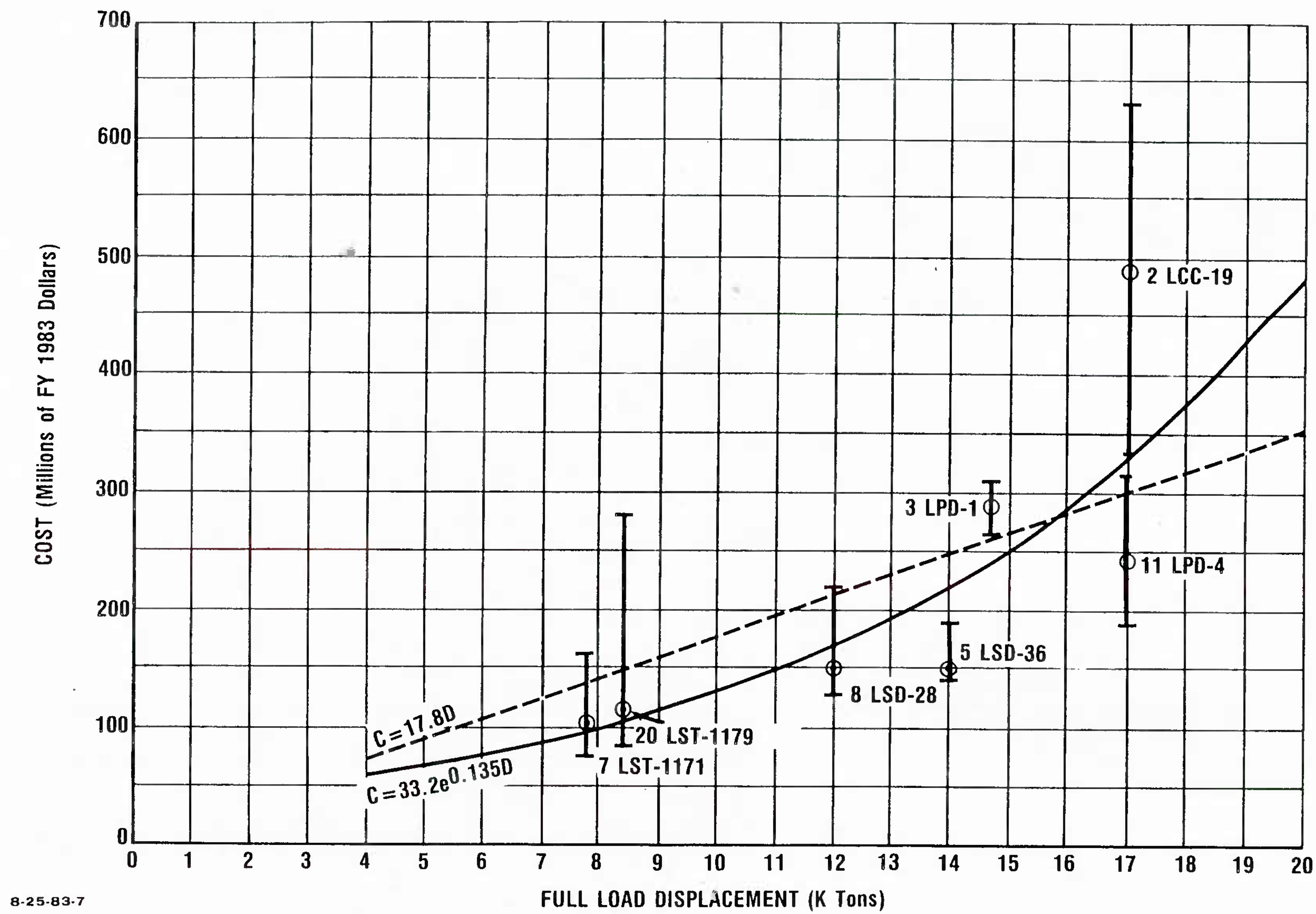

Figure 14. COST VERSUS WEIGHT CURVE FOR AMPHIBIOUS SHIPS

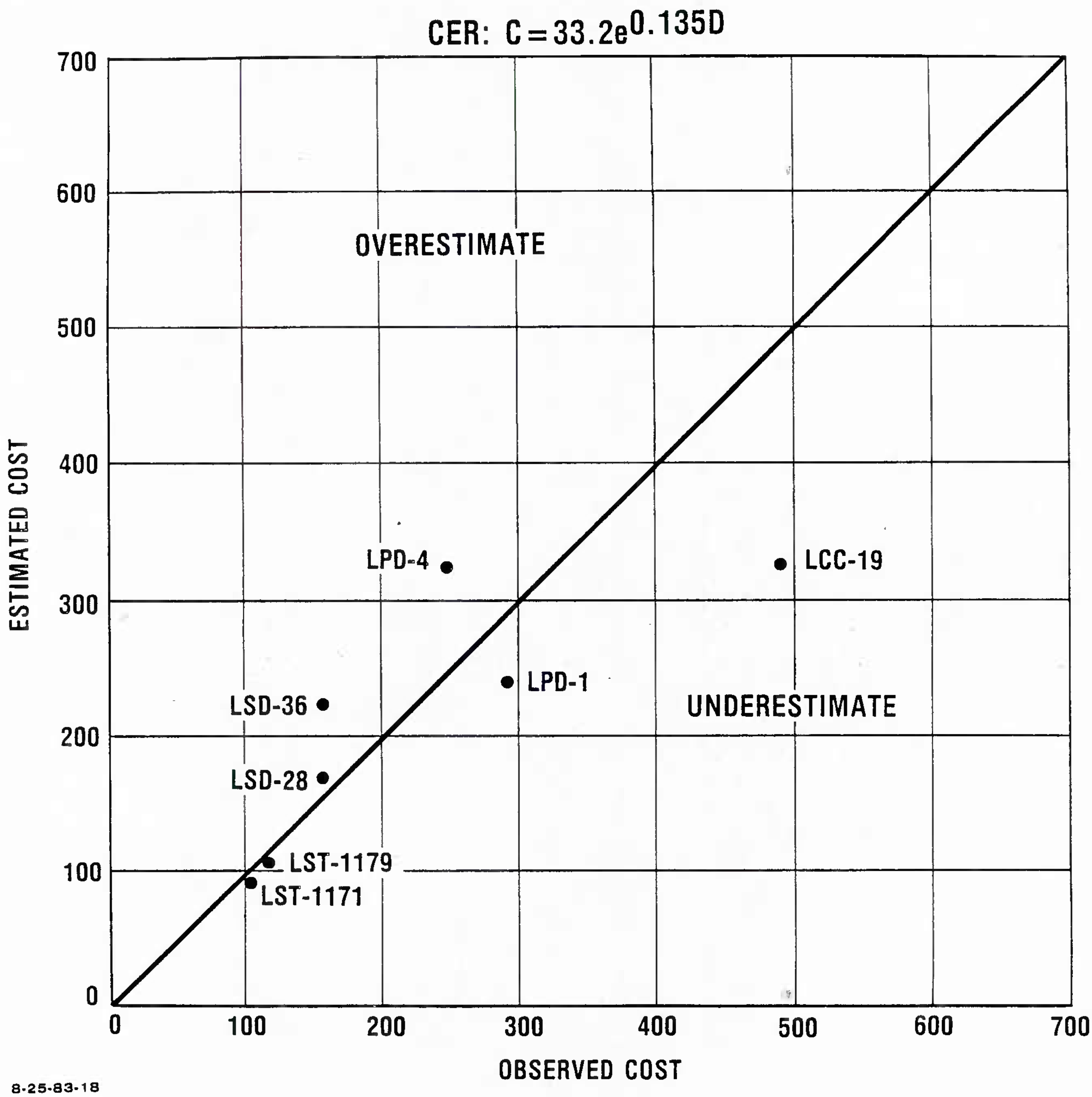

Figure 15. ESTIMATED COST OF AMPHIBIOUS SHIPS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING AN EXPONENTIAL EQUATION

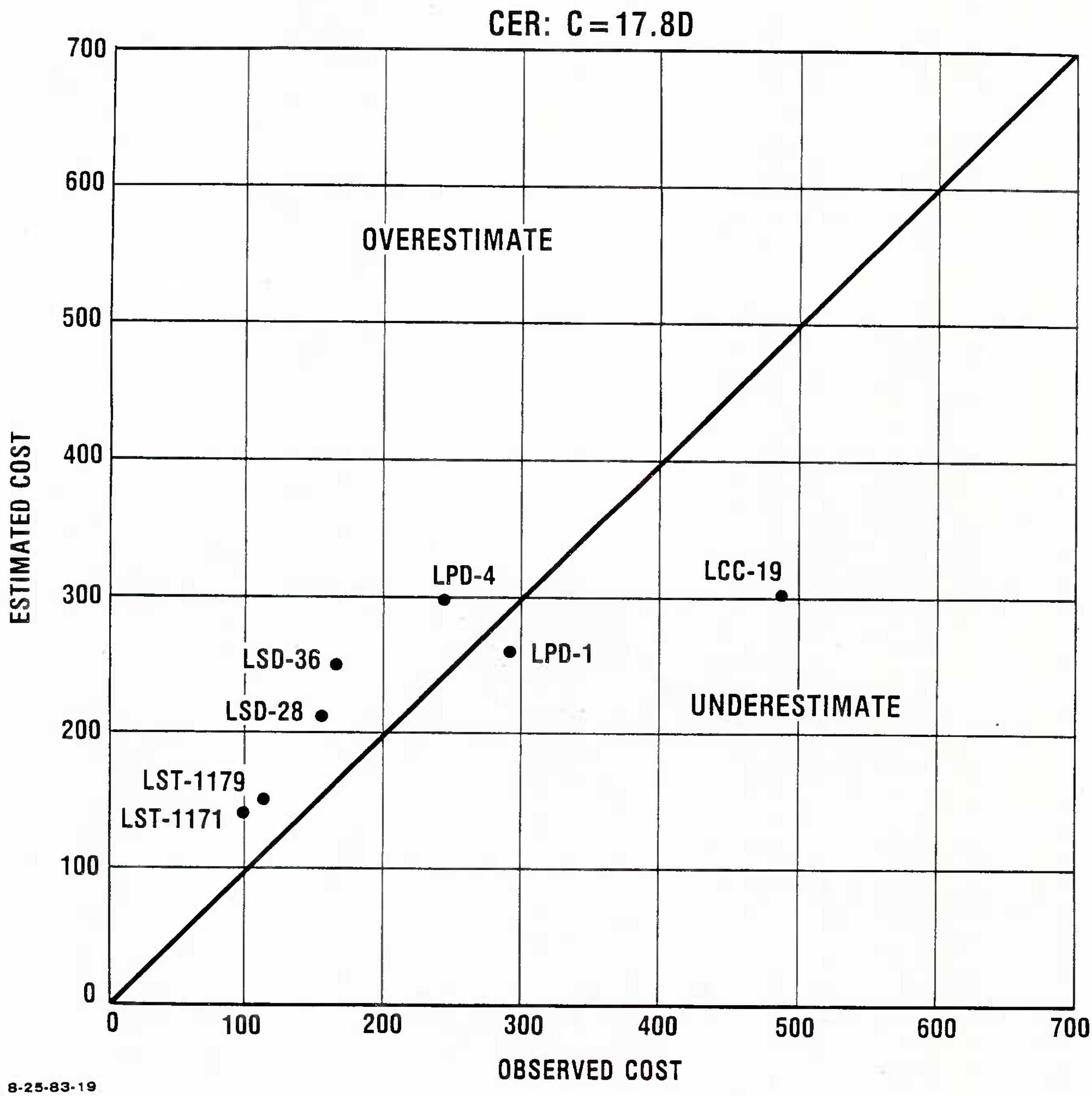

Figure 16. ESTIMATED COST OF AMPHIBIOUS SHIPS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

H. UNDERWAY REPLENISHMENT SHIPS

The ships that comprise this category are the AE, AF, AFS, LKA, AO, AOE, and AOR. As mentioned in the preceding section, the LKAs are included in this category because of their similarity in construction to AEs and AFs. One group of ships tends to cluster around a point at the intersection of 18,000 tons displacement and $140 million. The remaining AOs, AORs, and AOEs stretch out, but not in a consistent pattern.[1] Two equations result in curve fits that are about equal. They are a linear function $C = 37.4 + 5.54D$, and an exponential function $C = 92.2e^{0.024D}$. The category error using the exponential CER is negligible; the linear CER is about 2.6 percent. The average ship class absolute error for the exponential CER is 15.9 percent, and for the linear CER 18.1 percent. Both curves are displayed in Figure 17. The fit of the curves to the data is shown in Figures 18 and 19.

I. DESTROYER AND SUBMARINE TENDERS

The last category of ships for which an attempt was made to derive a CER is the AD and AS ships. Three different sorts of the data were fed into the curve fit model and none of the results produced a curve that would fit the data. An inspection of Figure 20 reveals that there is a variance of less than 3,700 tons displacement among the ship classes and less than $140 million in construction cost. The data in Figure 20 can be interpreted as tending to cluster about a single point which has the values of $370.6 million and 21,304 tons displacement.

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[1]The AO-143 class ships with a displacement of over 1.4 times that of the AO-177 class ships were constructed at about 77 percent of AO-177 class average cost. This is not a very good comparison because only the first three AO-177 class ships have been completed and are used to calculate the class average cost.

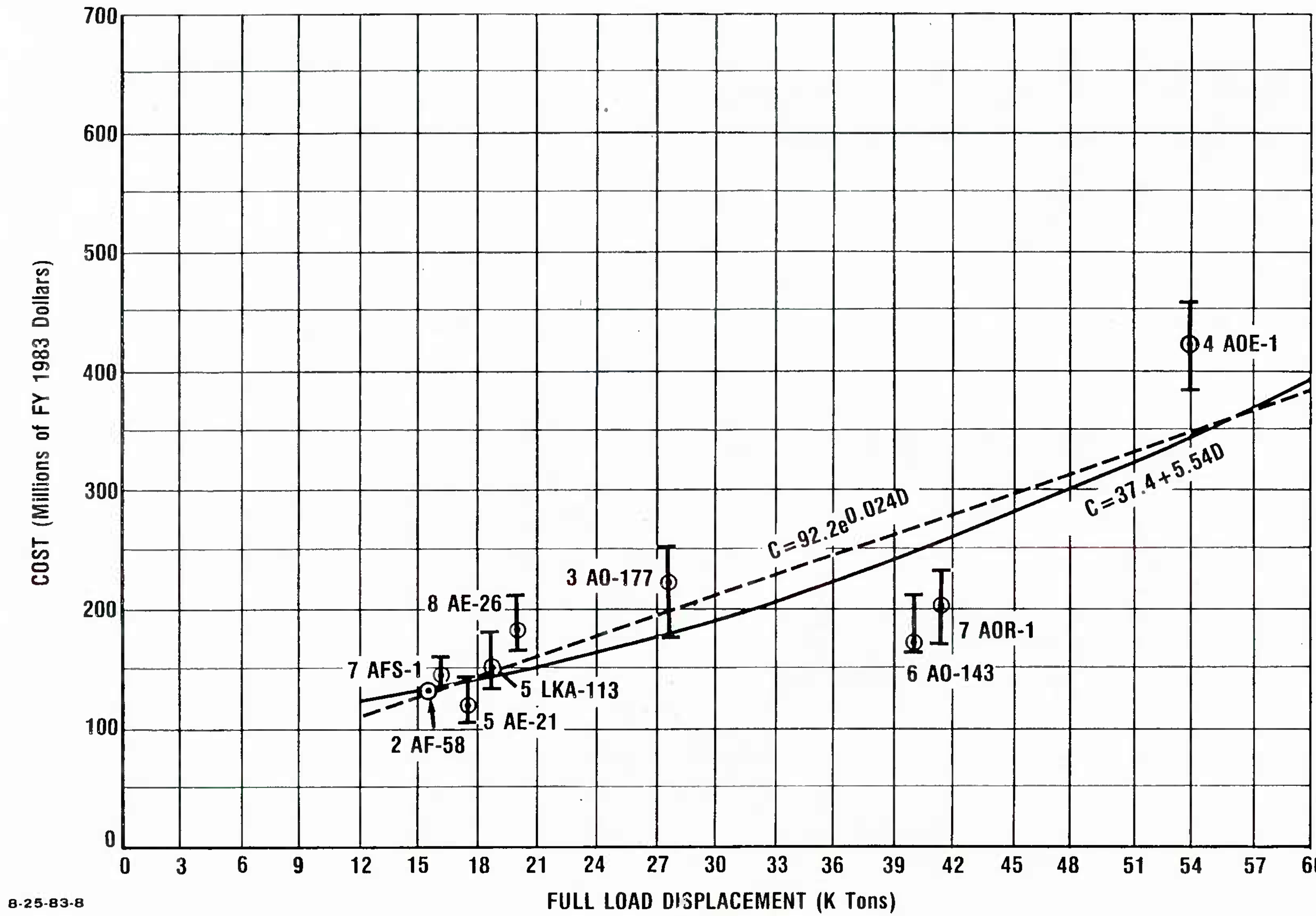

Figure 17. COST VERSUS WEIGHT CURVES FOR UNDERWAY REPLENISHMENT SHIPS

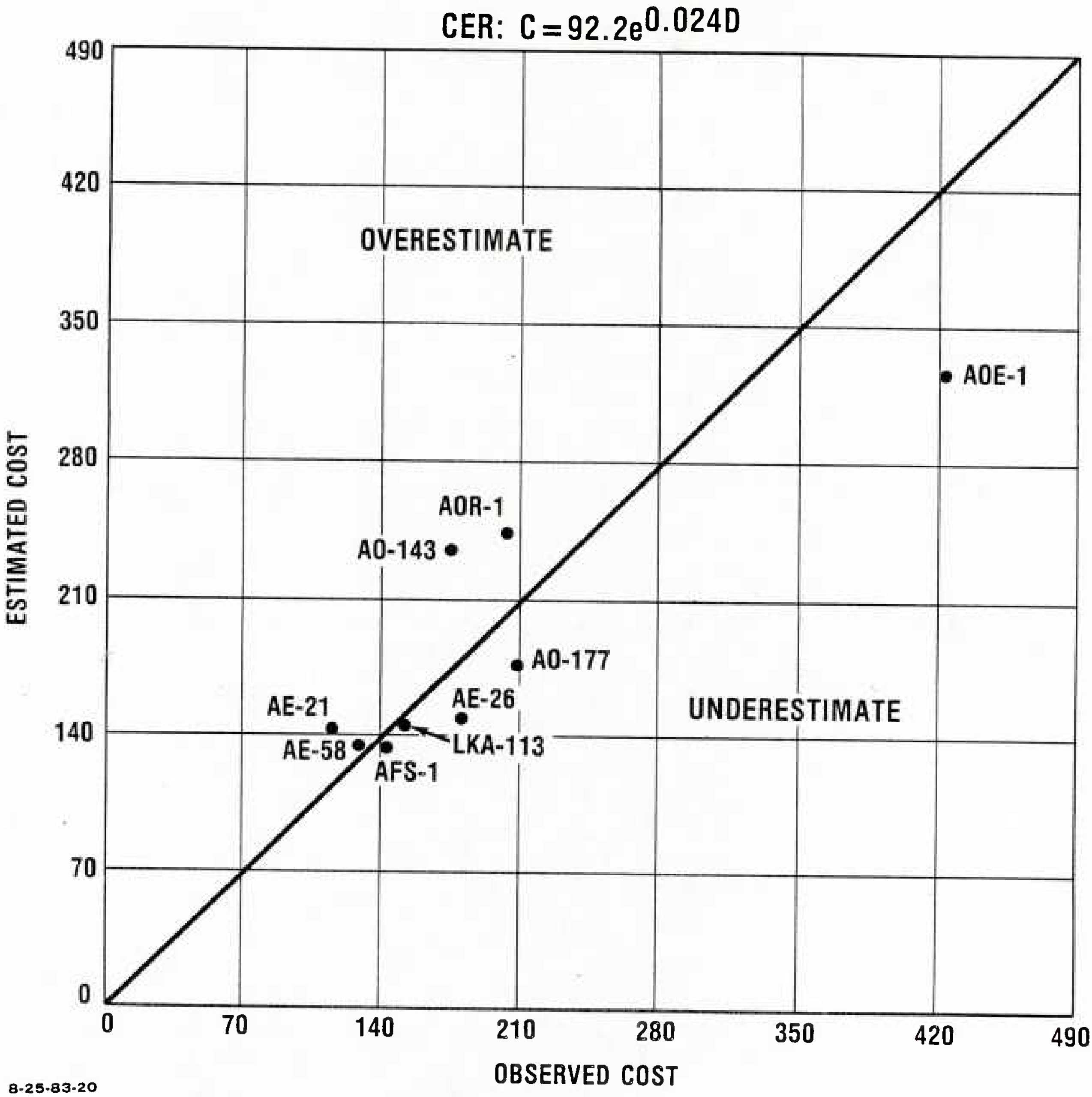

Figure 18. ESTIMATED COST OF UNDERWAY REPLENISHMENT SHIPS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING AN EXPONENTIAL EQUATION

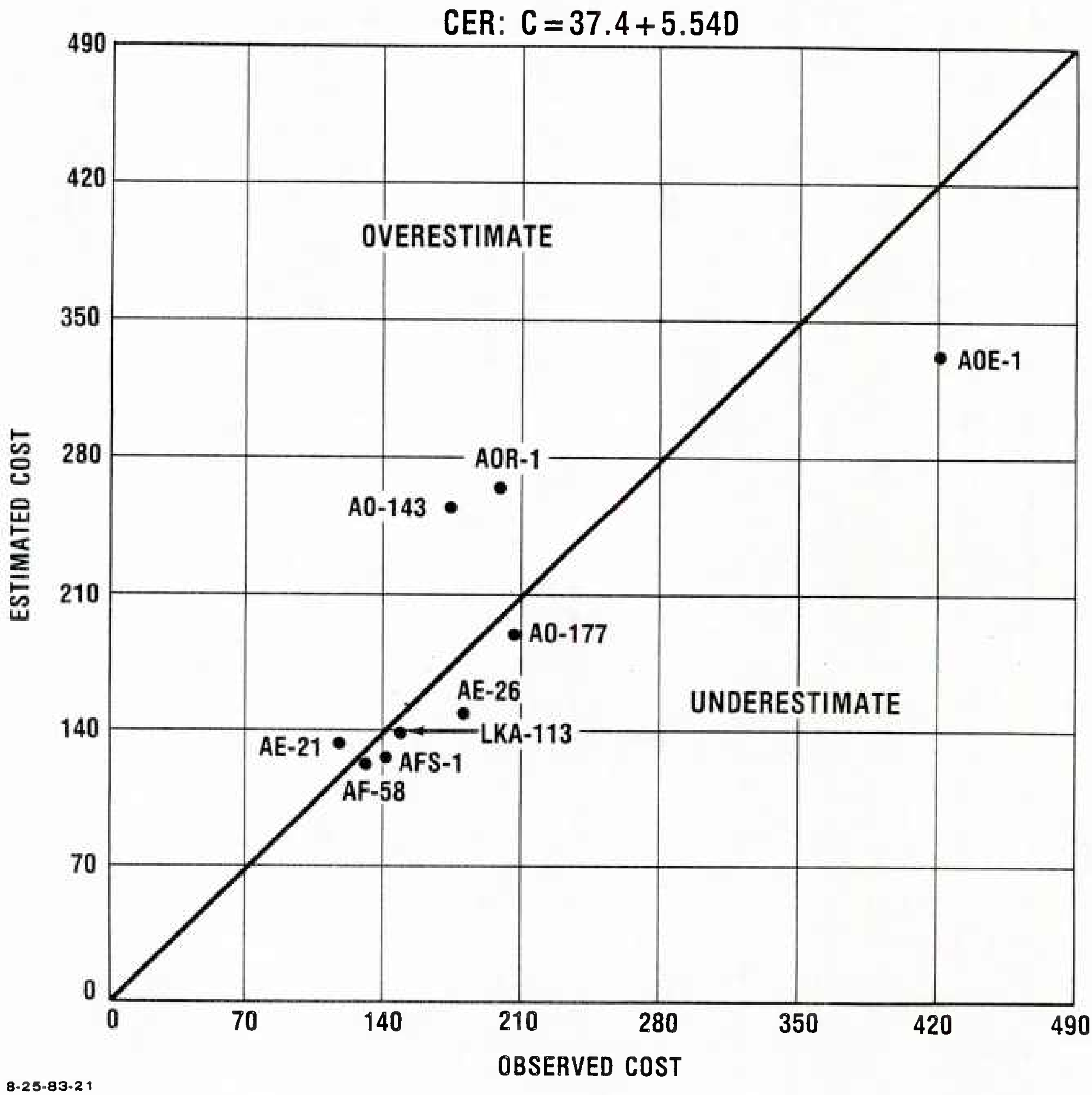

Figure 19. ESTIMATED COST OF UNDERWAY REPLENISHMENT SHIPS BASED ON WEIGHT VERSUS OBSERVED COST FOR SHIP PROCUREMENT USING A LINEAR EQUATION

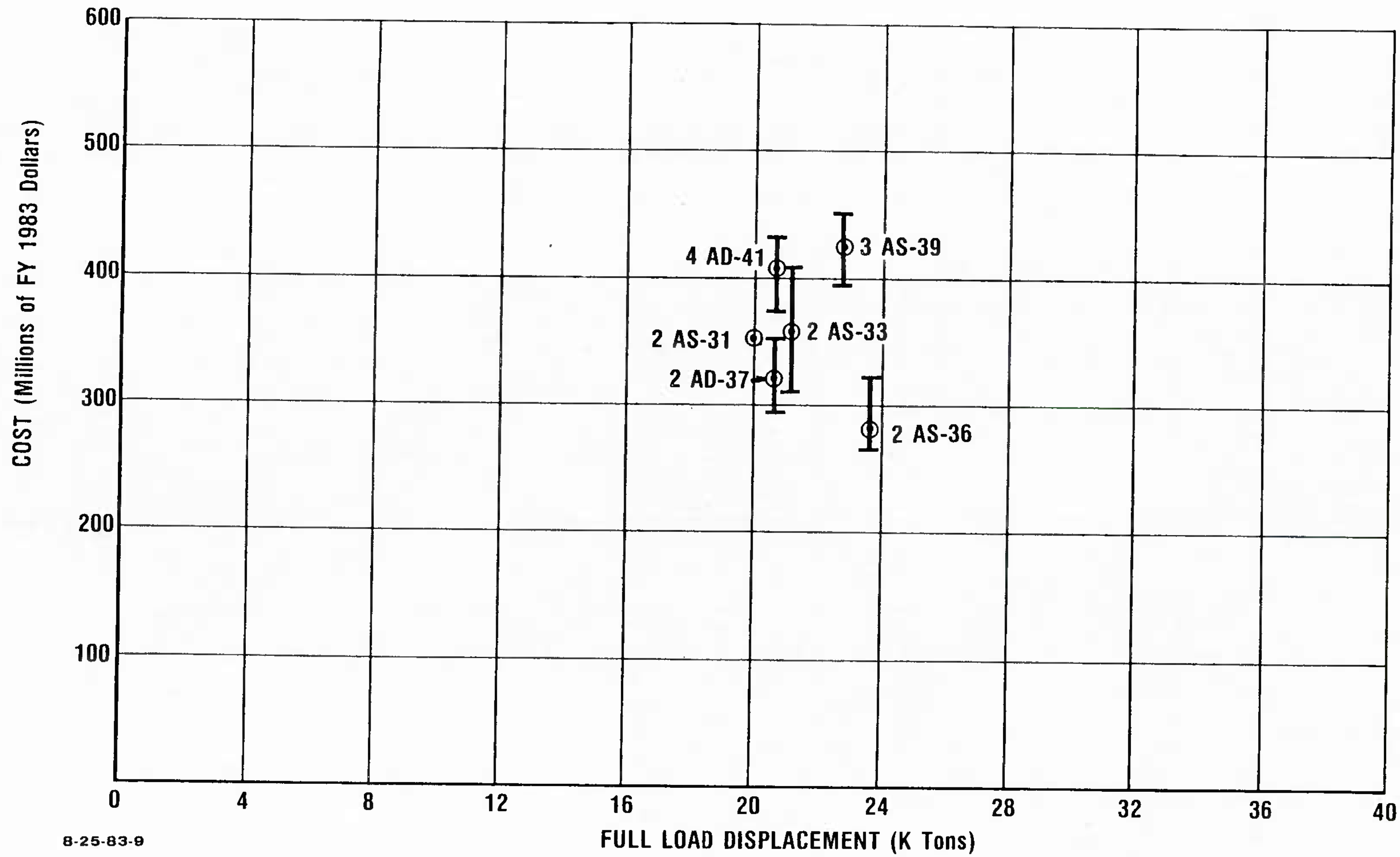

Figure 20. COST VERSUS WEIGHT DIAGRAM FOR DESTROYER AND SUBMARINE TENDERS

J. SUMMARY

The methodology used in the attempt to derive CERs for twelve categories of ships was presented followed by the results of entering cost and displacement data into three computerized curve fit equations. In some instances the data were too clustered to produce an acceptable CER; e.g., Destroyer and Submarine Tenders, and in other cases only one data point was available; e.g., CVN-68, SS-580, and CG-47 classes. In these latter cases assumptions were made that a parallel curve having a constant differential value was appropriate.

For each category of ship the range of errors between the CER estimate and the observed cost were identified and both the ship category error and the average ship class absolute error were presented. These data arranged by ship category are tabulated in Table 2.

REFERENCES

1. Pythagoras Cutchis and James H. Henry, Simple Relationships for Estimating Procurement Cost of U.S. Navy Ship Categories, IDA Paper P-1530, IDA, March 1982.

2. Estimated Cost to Build or Convert Naval Ships 442 005, Final Report 1952-1975, Naval Sea Systems Command, 22 September 1975.

3. Shipbuilding and Conversion, Navy, Shipbuilding Project Status Report as of December 1981, NE-700-70A, Naval Sea Systems Command, February 1982.

4. Shipbuilding and Conversion, Navy, Program Years FY 1962-1982, Naval Sea Systems Command, 10 March 1981.

5. Derivation of Cost Growth/Escalation, Etc., Amended Congressional Submission, Naval Sea Systems Command, 10 March 1981.

Appendix A

INDIVIDUAL SHIP PROCUREMENT COSTS

INDIVIDUAL SHIP PROCUREMENT COSTS*

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
AD-37	SAMUEL GOMPERS	354
AD-38	PUGET SOUND	296
AD-41	YELLOWSTONE	392
AD-42	ACADIA	375
AD-43	CAPE COD	431
AD-44	SHENANDOAH	432
AE-21	SURIBACHI	138
AE-22	MAUNA KEA	103
AE-23	NITRO	117
AE-24	PYRO	114
AE-25	HALEAKALA	116
AE-26	KILAUEA	189
AE-27	BUTTE	192
AE-28	SANTA BARBARA	179
AE-29	MOUNT HOOD	216
AE-32	FLINT	170
AE-33	SHASTA	170
AE-34	MOUNT BAKER	167
AE-35	KISKA	163
AF-58	RIGEL	129
AF-59	VEGA	129
AFS-1	MARS	160
AFS-2	SYLVANIA	139
AFS-3	NIAGARA FALLS	139
AFS-4	WHITE PLAINS	139
AFS-5	CONCORD	139
AFS-6	SAN DIEGO	135
AFS-7	SAN JOSE	134
AO-177	CIMARRON	252
AO-178	MONONGAHELA	196
AO-179	MERRIMACK	176
T-AO-143	NEOSHO	210
T-AO-144	MISSISSINEWA	165

*Table includes only those ships for which U.S. Navy historical cost data were available.

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
T-AO-145	HASSAYAMPA	165
T-AO-146	KAWISHIWI	165
T-AO-147	TRUCKEE	165
T-AO-148	PONCHATOULA	165
AOE-1	SACRAMENTO	453
AOE-2	CAMDEN	387
AOE-3	SEATTLE	441
AOE-4	DETROIT	414
AOR-1	WICHITA	224
AOR-2	MILWAUKEE	211
AOR-3	KANSAS CITY	179
AOR-4	SAVANNAH	176
AOR-5	WABASH	186
AOR-6	KALAMAZOO	198
AOR-7	ROANOKE	409
AS-31	HUNLEY	351
AS-32	HOLLAND	359
AS-33	SIMON LAKE	408
AS-34	CANOPUS	311
AS-36	L.Y. SPEAR	324
AS-37	DIXON	248
AS-39	EMORY S. LAND	451
AS-40	FRANK CABLE	396
AS-41	McKEE	429
CG-16	LEAHY	601
CG-17	HARRY E. YARNELL	388
CG-18	WORDEN	400
CG-19	DALE	483
CG-20	RICHMOND K. TURNER	415
CG-21	GRIDLEY	393
CG-22	ENGLAND	424
CG-23	HALSEY	419
CG-24	REEVES	394
CG-26	BELKNAP	523
CG-27	JOSEPHUS DANIELS	384
CG-28	WAINWRIGHT	369
CG-29	JOUETT	498
CG-30	HORNE	433
CG-31	STERETT	400
CG-32	WILLIAM H. STANDLEY	358
CG-33	FOX	396
CG-34	BIDDLE	348
CG-47	TICONDEROGA	1,369
CG-48	YORKTOWN	1,016
CGN-9	LONG BEACH	2,233
CGN-25	BAINBRIDGE	1,052
CGN-35	TRUXTON	832

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
CGN-36	CALIFORNIA	903
CGN-37	SOUTH CAROLINA	802
CGN-38	VIRGINIA	928
CGN-39	TEXAS	783
CGN-40	MISSISSIPPI	742
CGN-41	ARKANSAS	730
CV-59	FORRESTAL	1,491
CV-60	SARATOGA	1,604
CV-61	RANGER	1,310
CV-62	INDEPENDENCE	1,579
CV-63	KITTY HAWK	1,832
CV-64	CONSTELLATION	1,797
CV-66	AMERICA	1,629
CV-67	JOHN F. KENNEDY	1,737
CVN-65	ENTERPRISE	3,065
CVN-68	NIMITZ	2,939
CVN-69	DWIGHT D. EISENHOWER	2,386
DD-931	FOREST SHERMAN	286
DD-932	JOHN PAUL JONES	198
DD-933	BARRY	198
DD-936	DECATUR	219
DD-937	DAVIS	199
DD-938	JONAS INGRAM	199
DD-940	MANLEY	187
DD-941	DUPONT	169
DD-942	BIGELOW	169
DD-943	BLANDY	179
DD-944	MULLINNIX	179
DD-945	HULL	172
DD-946	EDSON	165
DD-947	SOMERS	166
DD-948	MORTON	175
DD-949	PARSONS	175
DD-950	RICHARD S. EDWARDS	174
DD-951	TURNER JOY	174
DD-963	SPRUANCE	469
DD-964	PAUL F. FOSTER	430
DD-965	KINKAID	396
DD-966	HEWITT	387
DD-967	ELLIOTT	322
DD-968	ARTHUR W. RADFORD	323
DD-969	PETERSON	317
DD-970	CARON	293
DD-971	DAVID R. RAY	308
DD-972	OLDENDORF	341
DD-973	JOHN YOUNG	315
DD-974	COMTE DE GRASSE	299

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
DD-975	O'BRIEN	288
DD-976	MERRILL	285
DD-977	BRISCOE	295
DD-978	STUMP	298
DD-979	CONOLLY	290
DD-980	MOOSBRUGGER	286
DD-981	JOHN HANCOCK	285
DD-982	NICHOLSON	271
DD-983	JOHN RODGERS	269
DD-984	LEFTWICH	270
DD-985	CUSHING	285
DD-986	HARRY W. HILL	275
DD-987	O'BANNON	270
DD-988	THORN	272
DD-989	DEYO	276
DD-990	INGERSOLL	280
DD-991	FIFE	279
DD-992	FLETCHER	305
DDG-2	CHARLES F. ADAMS	343
DDG-3	JOHN KING	261
DDG-4	LAWRENCE	274
DDG-5	CLAUDE V. RICKETTS	274
DDG-6	BARNEY	293
DDG-7	HENRY B. WILSON	262
DDG-8	LYNDE McCORMICK	265
DDG-9	TOWERS	280
DDG-10	SAMPSON	251
DDG-11	SELLERS	235
DDG-12	ROBISON	228
DDG-13	HOEL	246
DDG-14	BUCHANAN	240
DDG-15	BERKELEY	332
DDG-16	JOSEPH STRAUSS	245
DDG-17	CONYNGHAM	242
DDG-18	SEMMES	237
DDG-19	TATTNALL	273
DDG-20	GOLDSBOROUGH	234
DDG-21	COCHRANE	212
DDG-22	BENJAMIN STODDERT	216
DDG-23	RICHARD E. BYRD	216
DDG-24	WADDELL	225
DDG-37	FARRAGUT	448
DDG-38	LUCE	298
DDG-39	MACDONOUGH	302
DDG-40	COONTZ	439

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
DDG-41	KING	390
DDG-42	MAHAN	399
DDG-43	DAHLGREN	348
DDG-44	WILLIAM V. PRATT	345
DDG-45	DEWEY	300
DDG-46	PREBLE	298
FF-1006	DEALEY	139
FF-1014	CROMWELL	77
FF-1015	HAMMERBERG	74
FF-1021	COURTNEY	69
FF-1022	LESTER	68
FF-1023	EVANS	68
FF-1024	BRIDGET	66
FF-1025	BAUER	71
FF-1026	HOOPER	71
FF-1027	JOHN WILLIS	70
FF-1028	VAN VOORHIS	70
FF-1029	HARTLEY	70
FF-1030	JOSEPH TAUSSIG	70
FF-1033	CLAUD JONES	70
FF-1034	JOHN PERRY	54
FF-1035	CHARLES BERRY	74
FF-1036	McMORRIS	72
FF-1037	BRONSTERN	124
FF-1038	McCLOY	105
FF-1040	GARCIA	173
FF-1041	BRADLEY	143
FF-1043	EDWARD McDONNELL	141
FF-1044	BRUMBY	124
FF-1045	DAVIDSON	134
FF-1047	VOGE	280
FF-1048	SAMPLE	123
FF-1049	KOELSCH	137
FF-1050	ALBERT DAVID	121
FF-1051	O'CALLAHAN	110
FF-1052	KNOX	342
FF-1053	ROARK	152
FF-1054	GRAY	153
FF-1055	HEPBURN	154
FF-1056	CONNOLE	142
FF-1057	RATHBURNE	142
FF-1058	MEYERKORD	150
FF-1059	W.S. SIMS	138
FF-1060	LANG	148
FF-1061	PATTERSON	145
FF-1062	WHIPPLE	207
FF-1063	REASONER	136
FF-1064	LOCKWOOD	150

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
FF-1065	STEIN	151
FF-1066	MARVIN SHIELDS	154
FF-1067	FRANCIS HAMMOND	144
FF-1068	VREELAND	135
FF-1069	BAGLEY	151
FF-1070	DOWNES	155
FF-1071	BADGER	142
FF-1072	BLAKELY	128
FF-1073	ROBERT E. PEARY	172
FF-1074	HAROLD E. HOLT	148
FF-1075	TRIPPE	131
FF-1076	FANNING	150
FF-1077	OUELLET	138
FF-1078	JOSEPH HEWES	140
FF-1079	BOWEN	123
FF-1080	PAUL	123
FF-1081	AYLWIN	123
FF-1082	ELMER MONTGOMERY	123
FF-1083	COOK	128
FF-1084	McCANDLESS	130
FF-1085	DONALD B. BEARY	130
FF-1086	BREWTON	131
FF-1087	KIRK	143
FF-1088	BARBEY	133
FF-1089	JESSE L. BROWN	123
FF-1090	AINSWORTH	124
FF-1091	MILLER	124
FF-1092	THOMAS C. HART	125
FF-1093	CAPODANNO	127
FF-1094	PHARRIS	126
FF-1095	TRUETT	127
FF-1096	VALDEZ	127
FF-1097	MOINESTER	144
FFG-1	BROOKE	234
FFG-2	RAMSEY	202
FFG-3	SCHOFIELD	191
FFG-4	TALBOT	186
FFG-5	RICHARD L. PAGE	155
FFG-6	JULIUS A. FURER	157
FFG-7	OLIVER HAZARD PERRY	631
FFG-8	McINERNEY	227
FFG-9	WADSWORTH	277
FFG-10	DUNCAN	281
FFG-11	CLARK	205
FFG-12	GEORGE PHILIP	249
FFG-13	SAMUEL ELIOT MORISON	189
FFG-14	SIDES	244
FFG-15	ESTOCIN	184
FFG-16	CLIFTON SPRAGUE	237

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
LCC-19	BLUE RIDGE	632
LCC-20	MOUNT WHITNEY	349
LHA-1	TARAWA	847
LHA-2	SAIPAN	756
LHA-3	BELLEAU WOOD	779
LHA-4	NASSAU	850
LHA-5	PELILEU	835
LKA-112	TULARE	89
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LPD-1	RALEIGH	309
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*Only program year data were available for these three ships; therefore, only the average cost per hull can be derived.

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
LSD-36	ANCHORAGE	161
LSD-37	PORTLAND	163
LSD-38	PENSACOLA	155
LSD-39	MOUNT VERNON	157
LSD-40	FORT FISHER	142
LST-1156	TERREBONNE PARISH	113
LST-1157	TERRELL COUNTY	246
LST-1161	VERNON COUNTY	310
LST-1166	WASHTENAW COUNTY	260
LST-1170	WINDHAM COUNTY	64
LST-1171	DE SOTO COUNTY	80
LST-1173	SUFFOLK COUNTY	162
LST-1174	GRANT COUNTY	77
LST-1175	YORK COUNTY	83
LST-1176	GRAHAM COUNTY	103
LST-1177	LORAIN COUNTY	92
LST-1178	WOOD COUNTY	92
LST-1179	NEWPORT	282
LST-1180	MANITOWOC	176
LST-1181	SUMTER	174
LST-1182	FRESNO	101
LST-1183	PEORIA	98
LST-1184	FREDERICK	96
LST-1185	SCHENECTADY	96
LST-1186	CAYUGA	97
LST-1187	TUSCALOOSA	99
LST-1188	SAGINAW	103
LST-1189	SAN BERNARDINO	89
LST-1190	BOULDER	92
LST-1191	RACINE	89
LST-1192	SPARTANBURG COUNTY	91
LST-1193	FAIRFAX COUNTY	91
LST-1194	LA MOURE COUNTY	91
LST-1195	BARBOUR COUNTY	92
LST-1196	HARLAN COUNTY	92
LST-1197	BARNSTABLE COUNTY	93
LST-1198	BRISTOL COUNTY	102
PG-84	ASHEVILLE	31
PG-85	GALLUP	25
PG-86	ANTELOPE	57
PG-87	READY	56
PG-88	CROCKETT	18
PG-89	MARATHON	18
PG-90	CANON	18
PG-92	TACOMA	23
PG-93	WELCH	17
PG-94	CHEHALIS	20

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
PG-95	DEFIANCE	17
PG-96	BENICIA	23
PG-97	SURPRISE	17
PG-98	GRAND RAPIDS	21
PG-99	BEACON	17
PG-100	DOUGLAS	24
PG-101	GREEN BAY	18
SS-572	SAILFISH	191
SS-573	SALMON	133
SS-574	GRAYBACK	317
SS-576	DARTER	168
SS-577	GROWLER	225
SS-580	BARBEL	227
SS-581	BLUEBACK	143
SS-582	BONEFISH	125
SSBN-598	GEORGE WASHINGTON	1,223
SSBN-599	PATRICK HENRY	692
SSBN-600	THEODORE ROOSEVELT	763
SSBN-601	ROBERT E. LEE	650
SSBN-602	ABRAHAM LINCOLN	686
SSBN-608	ETHAN ALLEN	1,004
SSBN-609	SAM HOUSTON	638
SSBN-610	THOMAS A. EDISON	701
SSBN-611	JOHN MARSHALL	646
SSBN-616	LAFAYETTE	1,029
SSBN-617	ALEXANDER HAMILTON	605
SSBN-618	THOMAS JEFFERSON	562
SSBN-619	ANDREW JACKSON	684
SSBN-620	JOHN ADAMS	743
SSBN-622	JAMES MONROE	578
SSBN-623	NATHAN HALE	590
SSBN-624	WOODROW WILSON	648
SSBN-625	HENRY CLAY	596
SSBN-626	DANIEL WEBSTER	610
SSBN-627	JAMES MADISON	955
SSBN-628	TECUMSEH	586
SSBN-629	DANIEL BOONE	610
SSBN-630	JOHN C. CALHOUN	550
SSBN-631	ULYSSES S. GRANT	597
SSBN-632	VON STEUBEN	556
SSBN-633	CASIMIR PULASKI	594
SSBN-634	STONEWALL JACKSON	618
SSBN-635	SAM RAYBURN	561
SSBN-636	NATHANAEL GREENE	689
SSBN-640	BENJAMIN FRANKLIN	842
SSBN-641	SIMON BOLIVAR	552
SSBN-642	KAMEHAMEHA	608

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
SSBN-643	GEORGE BANCROFT	522
SSBN-644	LEWIS AND CLARK	539
SSBN-645	JAMES K. POLK	526
SSBN-654	GEORGE C. MARSHALL	506
SSBN-655	HENRY L. STIMSON	454
SSBN-656	GEORGE WASHINGTON CARVER	477
SSBN-657	FRANCIS SCOTT KEY	462
SSBN-658	MARIANO G. VALLEJO	549
SSBN-659	WILL ROGERS	463
SSBN-726	OHIO	2,454
SSBN-727	MICHIGAN	1,496
SSBN-728	FLORIDA	1,434
SSBN-729	GEORGIA	1,375
SSBN-730	RHODE ISLAND	1,515
SSBN-731	ALABAMA	1,451
SSBN-732	(UNNAMED)	1,445
SSN-571	NAUTILUS	460
SSN-575	SEAWOLF	458
SSN-578	SKATE	485
SSN-579	SWORDFISH	280
SSN-583	SARGO	294
SSN-584	SEADRAGON	295
SSN-585	SKIPJACK	479
SSN-586	TRITON	676
SSN-587	HALIBUT	489
SSN-588	SCAMP	337
SSN-589	SCORPION	387
SSN-590	SCULPIN	313
SSN-591	SHARK	317
SSN-592	SNOOK	307
SSN-593	THRESHER	874
SSN-594	PERMIT	526
SSN-595	PLUNGER	441
SSN-596	BARB	444
SSN-597	TULLIBEE	440
SSN-603	POLLACK	554
SSN-604	HADDO	442
SSN-605	JACK	686
SSN-606	TINOSA	645
SSN-607	DACE	387
SSN-612	GUARDFISH	512
SSN-613	FLASHER	514
SSN-614	GREENLING	482
SSN-615	GATO	467
SSN-621	HADDOCK	630
SSN-637	STURGEON	443
SSN-638	WHALE	454
SSN-639	TAUTOG	522

HULL NO.	NAME	COST (Millions of FY 1983 Dollars)
SSN-646	GRAYLING	566
SSN-647	POGY	579
SSN-648	ASPRO	436
SSN-649	SUNFISH	406
SSN-650	PARGO	573
SSN-651	QUEENFISH	379
SSN-652	PUFFER	437
SSN-653	RAY	377
SSN-660	SAND LANCE	691
SSN-661	LAPON	312
SSN-662	GURNARD	451
SSN-663	HAMMERHEAD	317
SSN-664	SEA DEVIL	334
SSN-665	GUITARRO	569
SSN-666	HAWKBILL	448
SSN-667	BERGALL	368
SSN-668	SPADEFISH	298
SSN-669	SEAHORSE	288
SSN-670	FINBACK	299
SSN-671	NARWHAL	700
SSN-672	PINTADO	471
SSN-673	FLYING FISH	344
SSN-674	TREPANG	290
SSN-675	BLUEFISH	291
SSN-676	BILLFISH	286
SSN-677	DRUM	468
SSN-678	ARCHERFISH	381
SSN-679	SILVERSIDES	335
SSN-680	WILLIAM H. BATES	367
SSN-681	BATFISH	338
SSN-682	TUNNY	371
SSN-683	PARCHE	355
SSN-684	CAVALLA	380
SSN-685	GLENARD P. LIPSCOMB	803
SSN-686	L. MENDEL RIVERS	418
SSN-687	RICHARD B. RUSSELL	421
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SSN-690	PHILADELPHIA	586
SSN-691	MEMPHIS	492
SSN-692	OMAHA	606
SSN-693	CINCINNATI	491
SSN-694	GROTON	575
SSN-695	BIRMINGHAM	472
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